

POPULAR MECHANICS

EXCLUSIVE:
Inside the
KOCH BROTHERS
Industrial Empire
What do they
actually
do?

HOW YOUR WORLD WORKS

**Indestructible
Drones**
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**The Underdog
Space Rocket**
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**Superfast
3D Printing**
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**Precision
Cancer
Treatment**
Page 74

Pluto!
Page 80

AND
**24 MORE
BREAKTHROUGHS
THAT WILL**

THE NEW ROBOTIC HAND

That isn't
a hand at all.
PAGE 71



BLOW YOUR MIND



JIMI HENDRIX // DODGE VIPER //
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AND WORK LIGHTS

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masthead-free
issue!


AMERICA'S
MAGAZINE
SINCE 1902

ON THE TRAIL OF THE

2016 CHEVROLET SILVERADO

WITH THE FOLKS WHO CREATED IT.

The 2015 Silverado 1500 was named **"Highest Ranked Large Light Duty Pickup in Initial Quality"** by J.D. Power¹ and the new 2016 Silverado comes from the same stock. The new face of strong, Silverado has a muscular front end that reflects its strength and capability. We sat down with the team of designers and engineers behind the new Silverado, the latest addition to the family of the most dependable, longest-lasting full-size pickups on the road.²





JOHN CAFARO

EXECUTIVE DIRECTOR,
GLOBAL CHEVROLET DESIGN

This Silverado makes some great advances using new lighting technology. How did this technology inspire the vehicle design?

Lamps are the windows to a truck's soul. They help give a truck its signature look—both during the day and at night. The new LED lamps on the 2016 Silverado gave us the opportunity to create a stronger, more expressive front end while giving our drivers a substantial improvement in night driving and overall visibility. It highlights how much technology is in the truck.

Truck design is one of the hottest areas in automotive design right now. What are some of the synergies between truck and other vehicle design?

Corvette and Silverado have been the iconic bookends for Chevrolet design for more than 50 years. In the past, they had completely separate design teams. We now have a lot more cross-pollination in our design teams and design work. You can see that influence especially in the hood and grille. These trim details allow customers to express personality. Grilles are like cowboy boots—they are your calling card.

***“Grilles are like cowboy boots –
they are your calling card.”***

John Cafaro

EXECUTIVE DIRECTOR, GLOBAL CHEVROLET DESIGN



TIMOTHY ASOKLIS

CHIEF ENGINEER – 2016 FULL-SIZE TRUCK,
CURRENT PRODUCT SUPPORT

The new Silverado was engineered with multiple enhancements, including articulating running boards. How do they work?

A new feature on Silverado, available articulating running boards automatically extend down and out from the sides of the cab to act like traditional steps. Just tap the foot control and they articulate rearward for access to the bed and its contents. No competitor offers this feature.

Towing is important in a truck. What advances set the 2016 Silverado apart when it comes to towing capability?

Throttle progression and grade braking are features that have come from our engineers studying the challenges of pickup truck towing in the real world. Throttle progression, along with our available 8-speed automatic transmission, makes accelerating with a heavy tow load both smooth and quick.

Using intelligent and adaptive algorithms, steep hills are more easily handled with Grade Braking Mode, which transfers some of the burden of slowing down and stopping from the brake pads to the engine and transmission.



¹ The Chevrolet Silverado LD received the lowest number of problems per 100 vehicles among large light duty pickups in the proprietary J.D. Power 2015 Initial Quality Study.SM Study based on responses from 84,367 new-vehicle owners, measuring 244 models and measures opinions after 90 days of ownership. Proprietary study results are based on experiences and perceptions of owners surveyed in February–May 2015. Your experiences may vary. Visit jdpower.com. ² Dependability based on longevity: 1987–April 2013 full-size pickup registrations.



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The grips, gear, and strategy you need. No mountains required.

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THE 2015 BREAKTHROUGH AWARDS

Our 11th annual celebration of the research, inventions, makers, scientists, and robotic cheetahs that are changing our world, including:

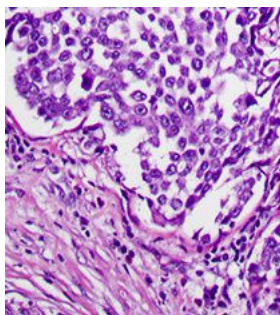
- A coffee cup made for space
- Biodegradable computer chips
- The landlocked researchers at the forefront of oceanic studies
- Bombproof concrete
- The pope

PLUS

74

EXCEPTIONAL

Instead of assigning treatments based on a type of cancer, doctors have started looking at the genetics of the person who has it. And it seems to be working.
BY KIRA PEIKOFF



82

THE UNDERDOG

NASA challenged the private space industry to create an unmanned rocket that can make ten spaceflights in ten days. Two of the finalists are aerospace giants. The third is a group of upstarts in the desert.
BY JOE PAPPALARDO



Flyability's Gimball drone can hover in disaster zones.



92

THE MONSTER

Koch Industries gets overshadowed by the politics of its owners. But what does one of the largest technology, manufacturing, and engineering companies in the country actually do? An exclusive look inside the behemoth that makes your toilet paper.

BY MICHAEL J. MOONEY

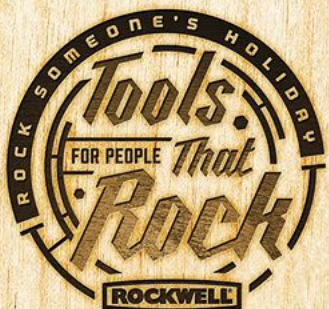
ON THE COVER: Empire Robotics' Versaball photographed by Ben Goldstein for Popular Mechanics.

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From the Editor

PERFECT DAY

It was a Tuesday like any other, except that it turned out to be a day that so embodied everything Popular Mechanics is about that I'm writing about it right here on this very page.

First, before my coffee had finished steeping (using the Canadiano wood pour-over [1] featured in our October 2014 issue), my older son was on the living-room floor cutting large shapes from old cardboard boxes. I said, "What are you up to?" He said, "Building a ship," without looking up.



Senior editor Roy Berendsohn pulled up a few minutes later, because we were testing a Kubota BX25D tractor [2] for a series of upcoming stories about all the things a person can do with such a machine. Roy hopped on and started clawing bucketsful of dirt from around the base of a rotten stump, and I grabbed a pickaxe to loosen some soil nearby, only to turn around and find my younger son—six—wearing his work gloves and asking to help. He wanted the pickaxe. My wife wasn't home, so I said okay, and he very ably and safely swung it a dozen times [3] before he stopped to play with a worm.

After lunch at the local farm stand, where they have a classic car meet every third Saturday, we were back at work on the stump when contributing editor Richard Romanski, who lives next door, walked over to check out the tractor. The stump was giving us trouble, so Richard disappeared and reappeared with two of the four chainsaws he tested for this issue (page 42) and started carving that thing up.

As I stood around trying to look useful while Roy and Richard worked, the older boy appeared at the front door carrying the ship [4] he had been working on all day, which was—and I know I'm the dad here—amazing. It was 3 feet long, covered with details, all constructed using cardboard and six kinds of tape. He had even tried to waterproof it.

The boys went out back to ride their Power Wheels Ford F-150s, I loaded some stump debris into my actual F-150, Roy drove off, Richard went to get a couple of IPAs, and I walked upstairs to find that the boys had dismantled the bathtub drain when they float-tested the ship. So I had to put that back together.

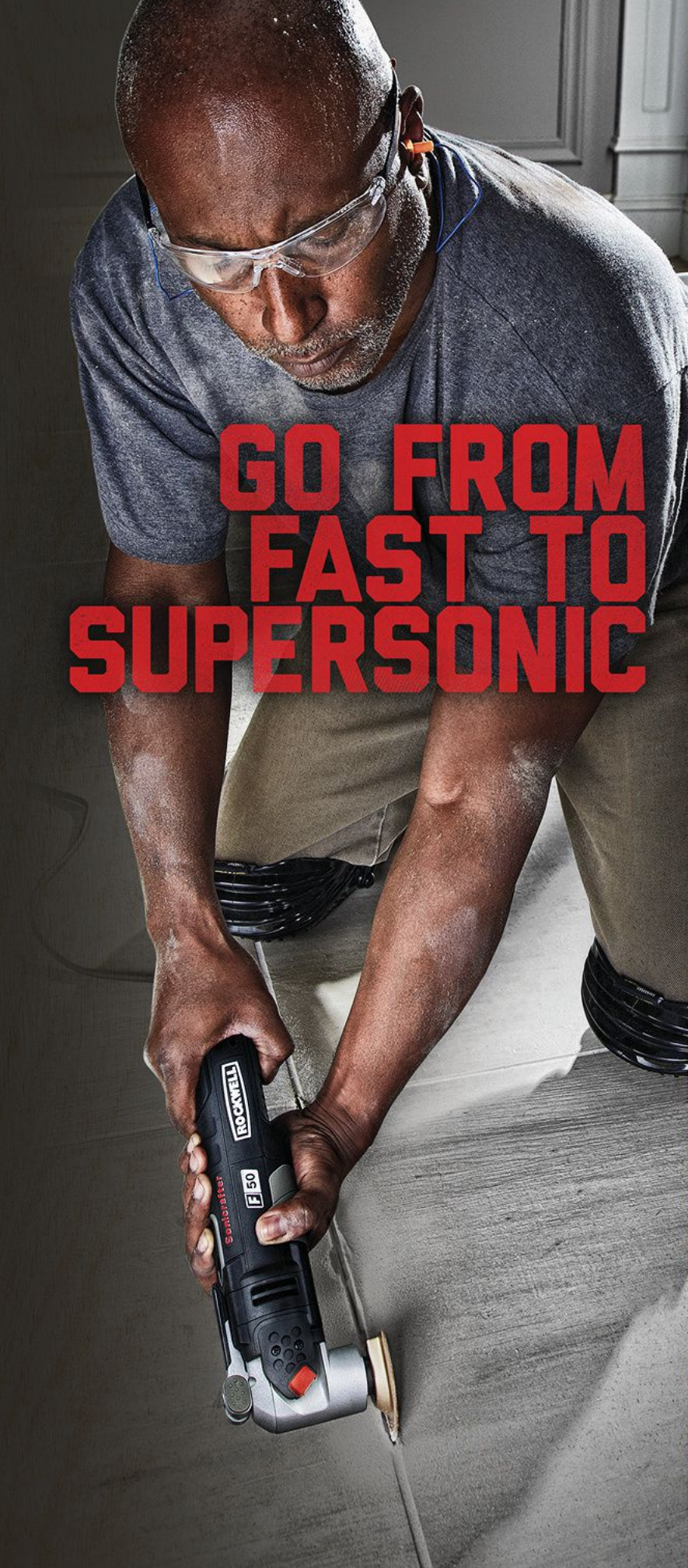
Back outside, Andy, who lives up the street (and who built the wine-barrel smoker in our September issue), stopped by and invited us all over for Taco Tuesday at his place.

I told him about my day, which was like a living, breathing issue of Popular Mechanics. I'm hoping to do it again soon.

Ryan D'Agostino

RYAN D'AGOSTINO
Editor in Chief





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F/50

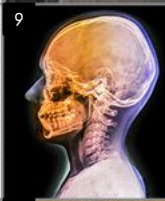
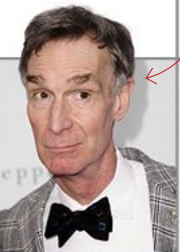
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Calendar / NOVEMBER

How to get the most out of your month.

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	
1 Daylight saving time ends. We fall back, so an extra hour of leaf cleanup! 		4 The new season of <i>All-American Makers</i> premieres on the Science Channel. Think <i>Chopped</i> meets <i>Shark Tank</i> , but for the DIY set.	5	6 The latest James Bond flick, <i>Spectre</i> , opens, allowing for long, glorious looks at the Aston Martin DB10.	7 	
8 The German physicist Wilhelm Röntgen discovered X-rays 120 years ago today.	9 	10 Run the self-cleaning cycle on your oven now, well ahead of Thanksgiving. If anything breaks, you have time to fix it.	11 Veterans Day. You can honor the service of our vets by helping those who need it most now. Just go to www.volunteer.va.gov .	12 	13 <i>The 33</i> , a movie about the Chilean miners trapped underground for 69 days in 2010, comes out today.	
15 This'll likely be the last mow of the lawn this season. When you're done, stow the mower away properly.	16 	17 The December/January issue of <i>Popular Mechanics</i> hits newsstands today.	18 The Leonids meteor shower peaks tonight, one of your last chances this year to view a meteor shower.	19 	20 	21 Have you started to stock your supply of rock salt and deicer yet?
22 And since you're prepping for winter, check the insulation in your home. Or replace it entirely. (See page 103.)	23 	24 Learn how complicated stuff works in the simplest language possible with <i>Thing Explainer</i> , by Randall Munroe.	25 Fortieth anniversary of the CT scan. 	26 Remember, amid any turkey-induced grogginess, that drive-assist is just that, an assist. Stay alert.	27 Bill Nye the Science Guy turns 60.	28 
29 Your tires may be all-season, but you and your car are safer switching to a set of dedicated winter tires as the snow approaches.						

SUN 11/8
WED 11/25
THIS MONTH IN MECHANICAL HISTORY
 On November 8, 1895, Wilhelm Röntgen accidentally discovered the X-ray while experimenting with a Crookes tube, an electrified, gas-filled tube. The first X-ray image used in the way we think of it was of the hand of Röntgen's wife, showing the bones and her wedding ring. Eighty years later Robert Ledley advanced radiology even further with the patenting of the first full-body computed-tomography scan, better known as the CT scan, to give us cross-sectional images of our insides.

SUN 11/15
HOW TO WINTERIZE A LAWN MOWER
 To take your mower out of service, sharpen the blade, fill the gas tank with stabilized or ethanol-free fuel, clean or replace the air filter, replace the spark plug, and change the oil so you don't have to remember to do it next spring. Maybe even pat it once on the handle and say, "See you next year."



11/17
IN NEXT MONTH'S ISSUE
 • A look at how technology is changing everything you know about high school
 • And how the U.S. is helping Iraq fight ISIS
 • Plus: Stupid or Amazing?

FRI 11/27
A WORD OF PRAISE FOR BILL NYE
 You or your kid can explain static electricity thanks likely to Bill Nye who, with his Saturday morning kids' show in the '90s, fashioned himself as America's pop scientist. More recently he's taken up the role of advocate for science and reason when it comes to some of the most politically charged issues of our day, personally debating prominent climate-change deniers and fighting for the removal of creationist theory from science textbooks. On the occasion of his 60th birthday, we salute him.

The Reader Pages

REMEMBER: We give \$100 for reader projects that we publish, and \$50 for original reader tips that we run. You can send both to editor@popularmechanics.com.

LETTER OF THE MONTH

I so enjoyed Joshua Ferris's "Learning to Fly" series (May through September). Like Ferris, who had just lost his father, I also had gone through one of the most difficult challenges of my life when I was learning. Flying proved to be the right thing to keep me grounded. I soloed after just nine hours of dual instruction. Looking back, I don't think I was ready. But are we ever ready for life's biggest challenges? Be it marriage, parenthood, the loss of a parent, or building our first deck.

Kudos to Popular Mechanics and Ferris for sharing this fun, slightly expensive, and scary endeavor. And a special thank you to the certified flight instructors out there who are willing to go aloft with us novices so that we, too, can realize the dream of flight.

Jim Callas, West Linn, Oregon

THE PROJECT ROUNDUP

Be it inspired from the pages of this magazine or be it your own creation, you guys have been hard at work.

COCKTAILS!

Instagram user @ekhoops scorched limes with a blowtorch to make Todd Maul's acid-minded gimlet recipe from the September issue.



A WAGON FOR A KID

Brandon Weisenberger of Carterville, Illinois, tweaked our wooden wagon plans (December/January 2015) to include caster wheels and fancy lettering for a gift for a two-year-old.



AND (WHOLLY ORIGINAL) SUBWOOFERS

Travis Effinger of Yacolt, Washington, has taken his home tinkering to the next level and made a small business for himself building hi-fi, pyramid-shaped subwoofers. Each sub takes him a week to complete. We haven't tried them ourselves, but if you want to inquire about your own set go to effingeraudio.com.



Letters to the editor can be emailed to editor@popularmechanics.com. Include your full name and address. Letters may be edited for length and clarity. **CUSTOMER SERVICE/SUBSCRIPTIONS** online: service.popularmechanics.com; email: popcustserv@cdsfulfillment.com; mail: Popular Mechanics, P.O. Box 6000, Harlan, IA 51593; **subscribe**: subscribe.popularmechanics.com.

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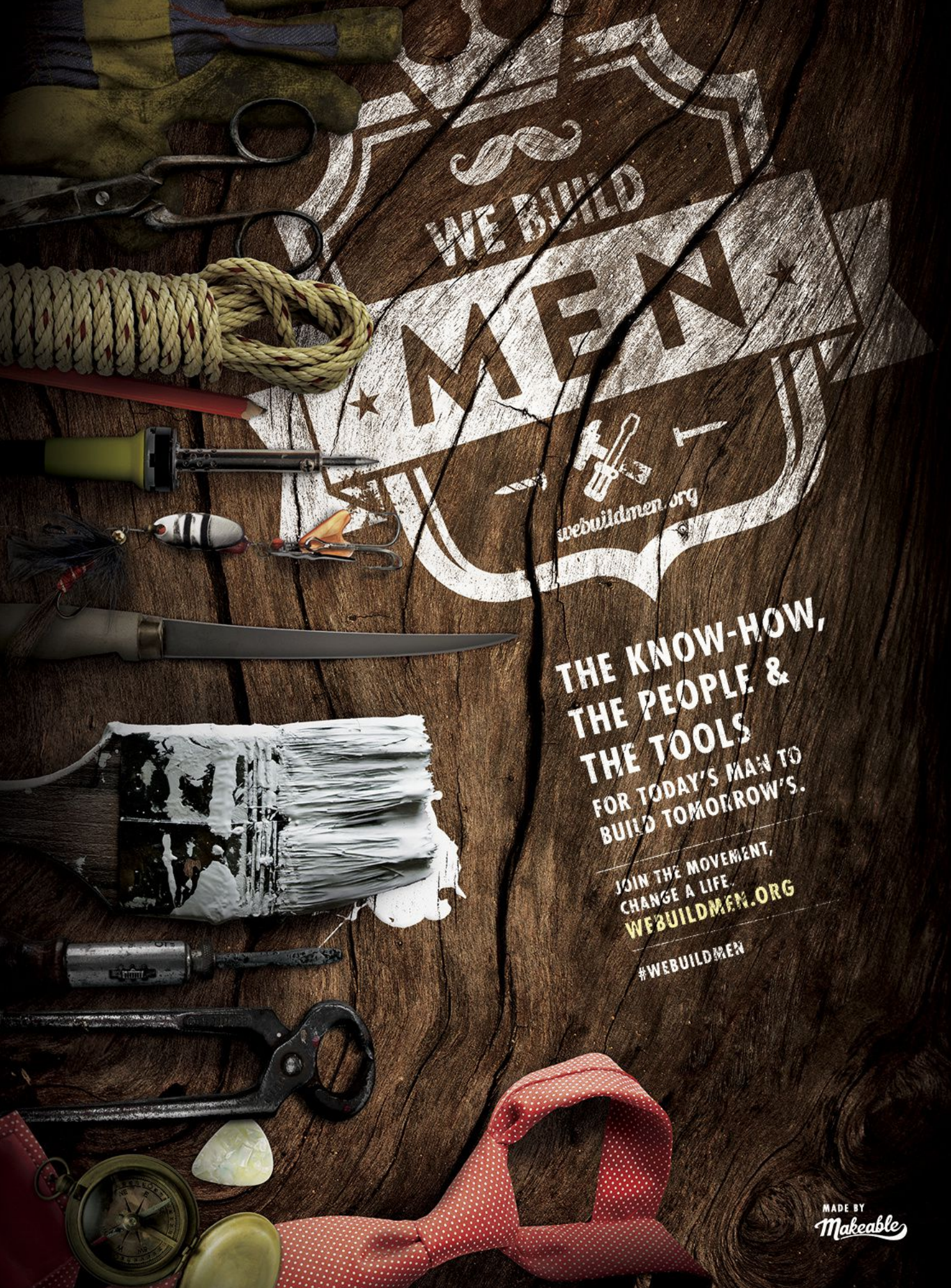


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The First Round Results

October 1933



WINNER!

86%

October 1946



14%

ROUND TWO!

A October 1933



B July 1957



Cast your vote now for Cover A or Cover B. The winning cover will square off against another challenger in the February issue.

- Email your vote to editor@popularmechanics.com.
- Or tweet it to [@popmech](https://twitter.com/popmech) using [#weirdcover](https://twitter.com/hashtag/weirdcover).

CORRECTION: In our story "How It Works: Desalinating Ocean Water" (September), we stated that General Electric is supplying the reverse osmosis technology for the Carlsbad Desalination Project. It is actually Dow Water & Process Solutions. We regret the error.

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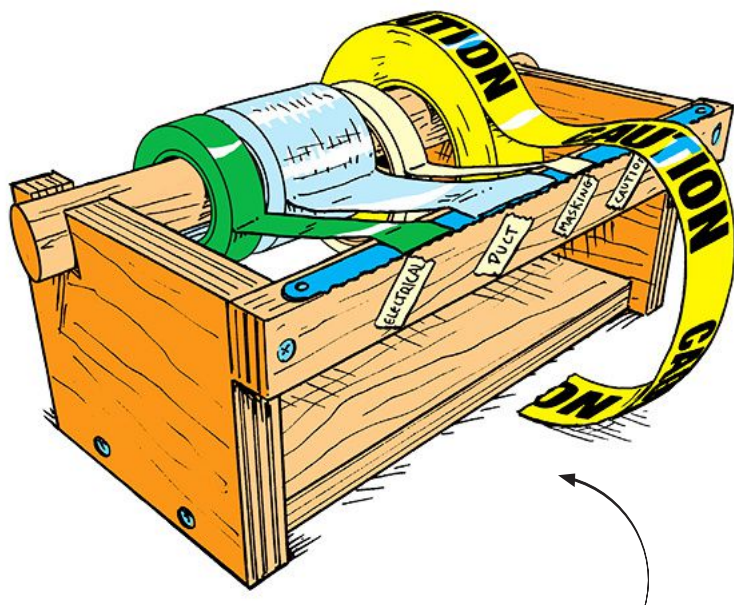


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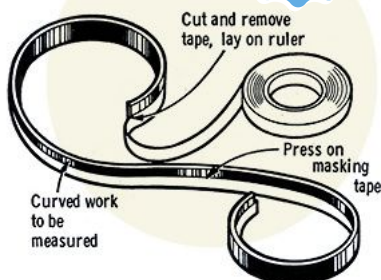
EASY
WAYS TO
DO HARD
THINGS



Handy Tape Dispenser From Spare Parts

It's time to organize the rolls of tape scattered around the house. Here's the best way: Cut a rectangular wood frame from scrap. Find a leftover dowel or length of rod or pipe. Cut it to the width of the wood frame, and cut slots in the frame to hold it. String rolls of tape along your improvised spindle. The finishing touch? An old hacksaw blade fixed on the front edge of the wood frame makes a cutting tool.

FROM
—THE—
ARCHIVES
(1969!)



Measure Abnormal Members With Solder or Tape

When cutting a straight material that will be curved in its final use—like chrome tubing for a toilet supply line or wood for the edge band of an elegant counter—it's difficult to know the exact length of material needed. Figure the measurements with a substitute material. For pipes or tubing, bend solder into the shape needed, then straighten and measure it. To follow the curve of an existing surface, press a strip of masking tape along it, then carefully remove the tape, lay it flat, and measure it.

POST-IT-PAD SHIM

When balancing a wobbly table or chair, grab a pad of Post-it notes. The ubiquitous office product is an ideal shim: It can be fine-tuned by removing individual notes, and paper won't scratch even the softest wood flooring. When in doubt, measure twice, peel once.



FOOD NOT JUST FOR EATING



PANTRY STAPLES FIX CAR BATTERY

Corrosion buildup on a vehicle's battery terminals can keep it from starting. The solution is in the pantry: Baking soda and water mixed into a paste and applied to the corroded terminals will dissolve the corrosion.



If you don't have baking soda, pour Coca-Cola over the battery instead. Scrub clean with a toothbrush, rinse the battery, throw away the toothbrush.



NUTS TOUCH UP FURNITURE

Nicks and scratches on wood furniture with a dark finish can be easily concealed. Rub the meat of an unsalted pecan or walnut on the damaged area. The nut's oils stain the wood.

Hacksaw Blade Is Flexible Straightedge

When marking guidelines for straight cuts on curved surfaces, a rigid straightedge won't do the trick. One handy substitute readily available in any shop: a hacksaw blade. Removed from the saw, its natural flexibility allows it to wrap around the curved object so its straight side can be traced. Mind the teeth.

Bicycle Rim in the Trash Bin Isn't Garbage

An outdoor garbage can takes a lot of abuse. When it gets bent out of shape, the lid won't stay on and both odors and refuse can escape. Prevent this by bolting an old bike rim into the opening to keep the can round. Remember to remove the spokes—they're recyclable.



• SHOP-SAFETY NOTE •

Use Drill's Clutch to Protect Hardware and Fasteners

When driving fasteners into soft woods, especially thin layers, it's easy to overdrive. In thick hardwoods, a fastener head is liable to shear off. Both problems can be prevented by properly using the torque-adjustment ring on a drill, which controls how much power goes to the bit. Lower numbers deliver less power, and higher numbers deliver more. Here's how to use it: Begin driving the fastener on the lowest torque setting—into a piece of test scrap, if possible. If the drill locks up before completely driving the fastener, incrementally increase the torque setting until the fastener is in place. Use this setting for the rest of the fasteners on the surface.

WITH THANKS TO: Mark Clement, clutch drill, MyFixitUpLife podcast.

FROM
—THE—
ARCHIVES
(1968!)

HOLSTER TOOLS WHEN ON LADDER

An empty bleach bottle is the perfect size to carry a drill or other power tool on a ladder. After ensuring that the bottle is empty, make an angled cut to take its bottom off. Turn it upside down and bolt it to a ladder's side. It keeps a tool handy but out of the way.

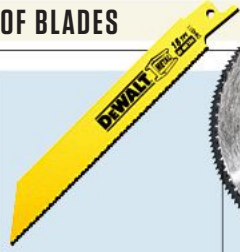


We are always looking for clever solutions to everyday problems. Email your shop notes to editor@popularmechanics.com and we'll pay \$50 if we print them.

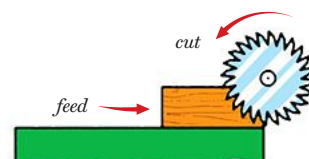
Saw Blades: The Finer Points

There are too many different kinds of saws to count, each with a specific purpose. They all come down to the same thing: teeth cutting material from a surface. Learn how saw blades work and choosing the right saw gets a lot easier.

TYPES OF BLADES

			
	BAND-SAW BLADE	BAYONET-STYLE BLADE	CIRCULAR BLADE
Motion	Teeth move in a line, in only one direction	Reciprocating or orbital	Rotating
Dimensions	Length, measured in inches, and teeth per inch (TPI)	Length, measured in inches, and teeth per inch	Diameter, measured in inches, and total number of teeth
Common blade materials	High-carbon steel, high-speed steel	Bimetal, high-carbon steel	High-speed steel, carbide (teeth)
Saw types	Band saw	Reciprocating saw, jigsaw, sternal saw	Circular saw, table saw, miter saw
Classic examples	Delta 14-inch band saw	Milwaukee Sawzall	Skilsaw

CUTTING MOTIONS



ROTATING

Teeth travel around the circumference of a circle, cutting in only one direction.



RECIPROCATING

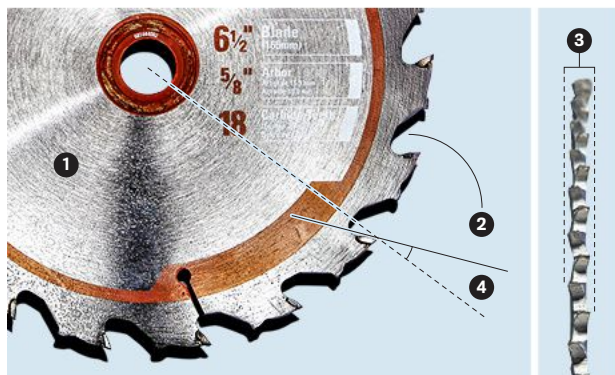
Teeth move back and forth in a line, and can potentially cut on both the push and pull strokes.



ORBITAL

In addition to linear movement, teeth move slightly up and down, describing an oval. Cutting forward and down at the same time produces a faster but rougher cut.

TOOTH GEOMETRY



- 1. PLATE**
The body of the blade.
- 2. GULLET**
The space between teeth. Helps clear cut material.
- 3. KERF**
Cut width. Thicker cuts require more power.
- 4. HOOK ANGLE**
Angle of the teeth. Forward rake makes a more aggressive cut.

ON TEETH

A blade with fewer teeth is said to be coarser than a blade with more teeth, and, generally speaking, should be used on softer materials.

WAYS TO CUT A BOARD



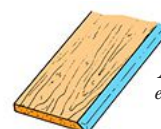
RIP
Parallel to the grain



CROSSCUT
Perpendicular to the grain



MITER
Diagonal to the grain



BEVEL
An angle on the edge of the board

THE CODE



Popular Mechanics has joined with Ford to bring you The Code, an editorial program inspired by the 2015 Ford F-150 and the individuals who drive them. From the skills every man should have, to the latest in gear, to smart news and entertainment, The Code brings the spirit of Built Ford Tough® to life.

WHAT ACTUALLY MAKES A 4x4 GOOD OFF-ROAD?

We all know what 4x4 means in a sense, but many people may not understand exactly what makes a 4x4 vehicle capable off-road—and what this means for those who've never taken their truck off pavement. What better way to illustrate this than by heading into the legendary terrain of America's off-road capital—Moab, Utah—in the latest 2015 F-150 truck (*shown at right*) with the FX4 off-road package? From learning to use features such as Hill Descent Control™ and available 360-degree cameras, to explaining what locking differentials are and why they're the key to rock crawling, we will showcase just what your stock 4x4 truck can do—with the added help of a little know-how, of course—over and across some of the country's most rugged and technical terrain.

READ THE COMPLETE STORY AT POPULARMECHANICS.COM/THECODE

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PHOTO BY T. C. WORLEY

FIVE HIGH-TECH WAYS TO MAKE YOUR GARAGE SMARTER AND SAFER



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NEST PROTECT SMOKE AND CO ALARM

Wi-fi enabled and app-driven, Nest's updated smoke and carbon monoxide detector Protect monitors your home 24/7, emails monthly reports, and won't annoy you when you burn the toast.



AUGUST SMART LOCK

Repairmen or in-laws coming to visit? August allows you to remotely give individualized access at preset times and monitors activity through a smartphone app.



MYQ GARAGE DOOR OPENER

You'll never wonder if you left the garage door open again. This little gadget works with your existing garage door to let you monitor and control your door remotely.



FUGOO STYLE BLUETOOTH SPEAKER

Whether you're changing the oil in your truck or building a playhouse for the kids, this rustproof, waterproof Bluetooth speaker will certainly make the task more enjoyable.

SEE ALL THE ABOVE ARTICLES AND MUCH MORE AT POPULARMECHANICS.COM/THECODE

NHTSA
5 STAR
OVERALL
SAFETY RATING



THIS KIND OF SAFETY IS NO ACCIDENT.

A 5-STAR OVERALL NHTSA SAFETY RATING*. IT DOESN'T GET ANY BETTER THAN THAT.

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THE F-150

/// **FORD.COM**

*Government 5-Star Safety Ratings are part of the U.S. Department of Transportation's New Car Assessment Program (www.SaferCar.gov).

**Remember that even advanced technology cannot overcome the laws of physics. It's always possible to lose control of a vehicle due to inappropriate driver input for the conditions.

Great New Stuff

The things you need in your life this month.



01

360FLY

Set this sphere, smaller and lighter than a baseball, at the center of the Thanksgiving table. At the end of the evening, send the virtual-reality experience it recorded to a relative overseas, who can watch it on YouTube 360—or show it to your fiancée on Google Cardboard to prepare her to meet your parents. If you haven't tried it, it's hard to overstate how convincing virtual reality can be, how even mundane events can be thrilling when experienced this way. The 360fly makes this new medium accessible to everyone. **\$400**

02

TISSOT T-TOUCH EXPERT SOLAR

Dawn sunlight peeping through the tent, energy-bar wrappers and a water bottle next to your face, adventure in your bones. You're alone, climbing a mountain, metaphoric or otherwise. You push up your sleeve to tap the watch that never dies, check the relative and absolute barometric pressure. The alarm sounds. Time to move. It's still charged from yesterday, the solar panels soaked by the sun. One less gadget to charge, one more gadget to help you win the day. **\$1,150**

03

LEGO FERRARI F40

What makes us want this version of the greatest supercar ever on our desk is how Lego and Ferrari managed to fit every one of the F40's essential details into a body that's only 10 inches long. The triple exhaust, the air ducts behind the doors, the pop-up headlights—all accounted for. **\$100**

04

LAGOSTINA LA RISOTTERIA

You will only buy this if (a) you enjoy eating risotto, the luscious Italian dish that's a pain in the neck to make (but worth it) because you have to stand there stirring rice for a half hour until it reaches the perfect, creamy consistency, and (b) you appreciate a good tool. The pan has a five-layer aluminum and stainless-steel core for even heat distribution, and the cherrywood lid seals in the moisture you need. Risotto: no longer a pain in the neck, still worth it. **\$200**





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Reorder light bulbs.

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Who is Nikola Tesla?

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weather and much more. Just ask.

INTRODUCING

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WOLVERINE 
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HOW YOUR WORLD WORKS



Brittle!

Dusty!

Corroded!

ASTRONAUT GEAR

THE FOREVER SPACESUIT

The garment Neil Armstrong wore when he became the first man to walk on the moon is deteriorating. Here's what the Smithsonian will do with the more than \$700,000 the public has pledged to fix it. BY KEVIN DUPZYK

PHOTOGRAPH
BY CHRISTOPHER
GRIFFITH



Conversation Starters for Smart People

To conserve weight for the journey home, Armstrong and the other astronauts left their life-support backpacks and moon boots on the moon. They're still there.

If, after the shelving of the space shuttle program, you feared that America had lost its adoration for space travel, this should help. In July, 46 years to the day after the first moon walk, the Smithsonian's National Air and Space Museum in Washington, D.C., started its first Kickstarter campaign, asking for money to preserve the spacesuit Neil Armstrong wore when he stepped off Apollo 11 onto the moon in 1969. Designed to withstand solar radiation, drastic changes in temperature, and objects traveling faster than the speed of sound, the suit is failing miserably at surviving the inevitability of time. The campaign requested \$500,000 to restore the suit before its unveiling at "Destination Moon," a permanent exhibit that will open in 2019. The goal was met in just five days. By the end of the campaign one month later, \$719,779 had been donated by more than 9,400 backers.

The Smithsonian could have raised this much money in the traditional manner, by schmoozing donors at galas, but in a way, asking the public for cash is appropriate. The Smithsonian Institution was founded with \$500,000 from a British scientist who never set foot in the United States but wanted to create an institution for "the increase and diffusion of knowledge among men." That all-for-one spirit is the same as the one that pushed us to explore space in the first place. And though few of us will ever set foot on the moon, the success of the Smithsonian's fund-raising effort proves that we'll spend the money to make sure future generations are still inspired by the effort it took to pull it off.

THE RESTORATION

Cathleen Lewis, curator of international space programs and spacesuits, and Lisa Young, objects conservator, explain how the museum will use the Kickstarter money to protect Armstrong's suit.

→ Rubber Protection

When NASA built the suit, it was concerned with only one thing: getting the astronauts to the moon and back. The suit designers didn't care about museum exhibits, so they chose to use a mix of natural and synthetic rubbers with a six-month life span. In fact, they couldn't order the suits too early or they would degrade before the mission was complete. Today the rubber has become brittle. Oxidation, UV radiation, and temperature are all factors in the deterioration, so a

new display case with a ventilation system will stabilize the rubber at 65 degrees Fahrenheit, 30 to 34 percent relative humidity, and about 100 lux.

→ Removal of Aluminum Corrosion

The aluminum on the suit—primarily the red and blue buttons and arm disconnects—has oxidized and could become riddled with corrosion pits. Conservators have tested several removal options, including lasers, air abrasion, and old-fashioned hand tools. Everything they've tried has removed more of the original material than they'd like, so a portion of the Kickstarter money will be used to test corrosion inhibitors used in military and commercial applications. The compound they identify will be applied throughout the spacesuit collection,

which includes 400 pairs of gloves with aluminum components.

→ Preservation of Moondust

Conservation isn't about making the suit "like new," but preserving the state it was in when Armstrong got home. Like any article of work wear, the suit needs a good cleaning, but the moondust on the suit can stay. Conservators will use tweezers under a microscope or a tweezer vacuum, which uses a tiny suction tip to pick up delicate materials, to remove debris without disturbing the dust. This actually isn't so difficult: The lack of atmosphere on the moon creates very sharp dust particles. These have embedded themselves deeper in the suit's fabric than a surface cleaning should reach.

→ Stripping of Surface Coatings

Sometimes past preservation is the enemy of current conservation: Protective coatings, such as those applied to Armstrong's suit before it was allowed on a post-mission tour, often break down before the object itself. Research will determine exactly what coatings have been applied—conservators suspect Teflon—and whether mechanical or chemical means should be used to remove them.

→ Support

The suit needs a mannequin to hold it up. But because the suit doesn't fully unzip, the mannequin has to be assembled inside it. Additionally, the support system needs to hold the gloves and helmet, which can't be attached—in part because residual lunar dust can lock up their couplings. Colleagues throughout the Smithsonian are building a prototype mannequin, which will then be replicated for the rest of the museum's spacesuits.

→ Ventilation

As materials in the suit break down, they undergo a process called off-gassing, in which they emit harmful chemicals in gaseous form. Rubber, for example, off-gasses hydrogen chloride, which is highly acidic and damages other materials in the suit. To combat this, the suit's new display case will include a chemical scrubber to bond with the gases and pull them out of circulation. Finding a suitable scrubber will be a challenge, as the molecules conservators need to trap are much smaller than typical pollutants.



Smithsonian Institution objects conservator Lisa Young inspects aluminum fittings on Neil Armstrong's suit for the presence of chlorides.



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*proven on 3 day beards

MOVIES

A SLASHER FLICK FOR 2015

In a genre that seems all but exhausted, one director had a crazy idea: Why not shoot a horror film with a robot camera?

BY JACQUELINE DETWILER

The directors of scary movies employ a number of techniques to manipulate the audience's emotions—the close-up, the wide-angle, the long take, the jump cut. Todd Strauss-Schulson, director of *The Final Girls*, a campy meta-style horror-comedy, out October 9, wanted to do something different. His idea was to mimic the characters' fear by producing a scene that tumbled and rolled like a visual panic attack. The problem: No human camera operator could perform the moves he needed, even on a crane. Instead, Strauss-Schulson, who had been experimenting with robotic cranes while making short films, rented a Genuflex MK III by General Lift, a programmable robot that can track 7 feet per second and swing, pan, tilt, and roll 360 degrees, all while automatically focusing a camera. It can also produce multiple takes with inhuman precision, repeating the exact same motions over and over within fractions of a millimeter, like a robot in a factory.

The Genuflex is primarily used to create visual effects—multiplying extras to create fake crowds, for example, and creating slow-motion shots of moving vehicles. Strauss-Schulson used it to follow six of *The Final Girls*' main characters while they attempt to use a booby trap to foil a maniac with a machete. Over three days in a humid cabin in Baton Rouge, Louisiana, the technicians programmed the crane to move through a shot, then established speed and focus. Next they ran each take at half speed so the actors could practice hitting their marks before the camera hurtled to within—in some cases—inches of their faces. “That’s the fun engineering stuff,” says Strauss-Schulson. “You worry: Is the track long enough? Is it going to knock into the wall? Is it gonna hit that guy over there?” Finally, the staff got each of four shots necessary to complete the scene—full speed, with no actors knocked unconscious. The MK III’s engineers, accustomed to planning dull technical shots, had a blast. The resulting paroxysm of an action sequence, one that would be easy to adapt to other movie genres, is novel and great. Also: pretty damn scary.



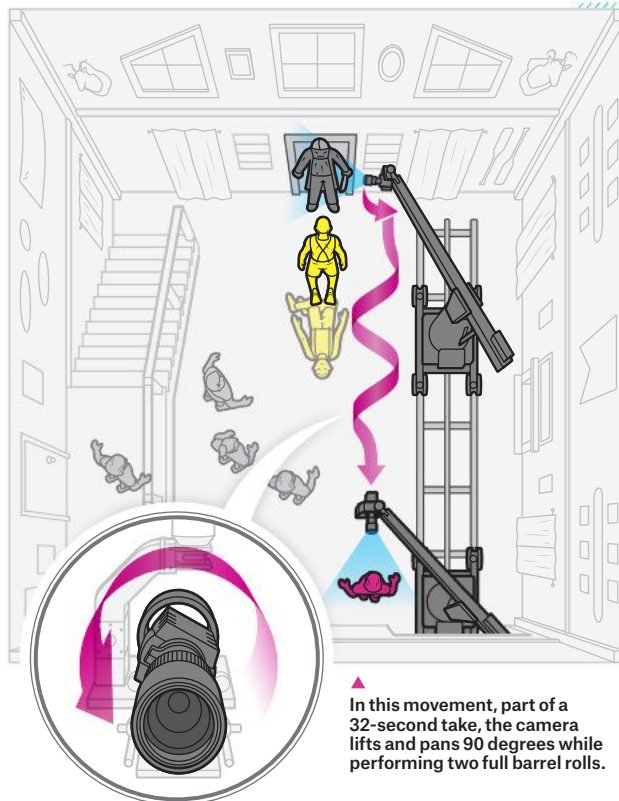
+ **HISTORY: AN UPDATE** The real-life friendship between humorist Mark Twain and explorer-of-Africa Sir Henry Morton Stanley so fascinated late Pulitzer Prize-winning novelist Oscar Hijuelos that he spent more than a decade researching and fictionalizing it, working on revisions until the day before his death in 2013. The historical novel *Twain & Stanley Enter Paradise*, out November 3, is the result.



↑ The daughter of a horror-movie scream queen (pictured) becomes trapped in one of her mom's old movies in *The Final Girls*.

The Robot Take

A few of the motions the Genuflex MK III makes after the bad guy, Billy, stabs one of the main characters.



▲ In this movement, part of a 32-second take, the camera lifts and pans 90 degrees while performing two full barrel rolls.

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H/T

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M/T
COMING SOON

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FALKEN
TIRE
ON THE PULSE

The Ozone Layer?

Surprise! It's still there.

Remember the 1980s, when the greatest threats to civilization were crack cocaine, ozone depletion, and Spandex? We actually solved one of those problems. According to reports from the United Nations, not only is the ozone layer recovering, it could be restored to 1980s levels as soon as 2050. This good news is largely due to the Montreal Protocol, a treaty that banned ozone-depleting chlorofluorocarbons (CFCs), often used in aerosol sprays and refrigerants, in 1987.

Hold those high fives, lovers of air. After the agreement many manufacturers replaced CFCs with hydrofluorocarbons (HFCs), which lack the chlorine in CFCs that harms ozone but still trap energy in the atmosphere, contributing to global warming. The situation is worrisome enough that the Obama administration recently mandated that any company able to switch to a safer compound must do so.

James Burkholder, a National Oceanic and Atmospheric Administration research scientist, says a likely substitute is a class of chemicals called hydrofluoroolefins (HFOs). These have global-warming potential similar to HFCs but last only about a week. (In comparison, a common HFC refrigerant in cars has a lifetime of about 13 years.)

There's no set time line for the transition to HFOs. Manufacturers will have to modify their factories to work with the new compound, which could take years. In the meantime maybe scientists can eliminate more nefarious threats from the '80s, such as Tom Cruise. —ANDREW DEL-COLLE

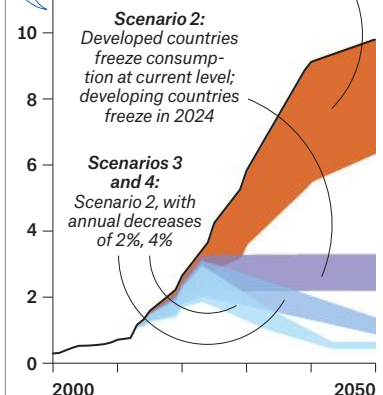
GLOBAL HFC PRODUCTION SCENARIOS

Carbon dioxide equivalent, a measure of potential global warming (in billions of metric tons per year)

Scenario 1:
HFC consumption left unchecked

Scenario 2:
Developed countries freeze consumption at current level; developing countries freeze in 2024

Scenarios 3 and 4:
Scenario 2, with annual decreases of 2%, 4%



PLASMA ACTUATORS

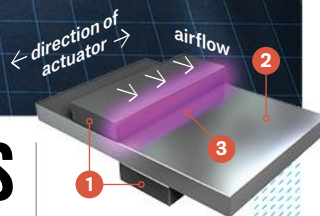
Extremely complicated physics explained with the help of semitrucks.

Formula One cars are the vehicle world's birds of prey—sleekly exploiting aerodynamics to overtake weaker Formula One cars. Long-haul trucks, on the other hand, are built more like turkeys, as if drag, the air resistance that impedes a vehicle's motion, doesn't hamper semis the way it does race cars. Unfortunately, that's not true. Some 66 percent of a semitruck's gasoline goes to combating drag. Plasma Stream Technologies, a company using science developed at the University of Notre Dame, thinks it has a solution: Use a plasma actuator to alter airflow—turning a turkey into a hawk—without actually changing the shape of the truck. Sounds cool, but, uh, what's a plasma actuator?

According to Notre Dame engineering professor Thomas Corke, when an insulating material such as Teflon is sandwiched between two staggered, electrically charged copper plates, one exposed to air and the other trapped behind the Teflon, the surrounding air transforms into the fourth state of matter, plasma, which means that it develops an electric charge. The exposed electrode repels similarly charged plasma, pushing it toward the electrode with the opposite charge. As the plasma moves, it sucks neutrally charged air along with it, creating an air current the same way a fin or a spoiler would. —CAMERON JOHNSON

The truck on the left doesn't divert airflow, so air turbulence at the rear creates significant drag, slowing the vehicle down and wasting fuel. Plasma actuators on the top and sides of the truck on the right change the angle of airflow to mimic that of a much more aerodynamic vehicle, relieving turbulence. Reducing drag on the rear of a truck alone could reduce fuel costs by 12 percent.

The same stuff that's in lightning!



1. Electrically charged copper plates
2. Insulating dielectric layer (such as Teflon)
3. Plasma

WILL PRINTING STUFF ALWAYS SUCK?

There's a special place in hell for the grifter who invented the printer cartridge. You buy this necessary gadget, run out of cyan ink at 2:00 a.m. the night before an interview, and next thing

you know you're swiping your credit card for 50 bucks under the sad fluorescent lights of an office supply store. Thanks to Epson, you can now spend around \$400 for an EcoTank printer, which

has side-mounted reservoirs that hold a year's worth of ink. It costs about half what you would pay for a cartridge-based printer over the course of its life. Take that, Big Printer!

It's a welcome advancement, but I'm still holding out for the day printing ends. Plane tickets, movie

tickets, documents to be signed, all of that can be done with a smartphone now.

Printing is still essential for some tasks (shipping labels, for example), but I trust that one day it will disappear. Then we can save our clunky ink-jets for sending sonnets through the mail.

—ALEXANDER GEORGE



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IT'S DOABLE

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worldwildlife.org/solar

DRINKS

WHY YOUR NEXT GIN SHOULD BE BROWN

Gin-makers are stealing ideas from bourbon, and that is a very good thing. **BY FRANCINE MAROUKIAN**

Doing something new with gin has usually been a bad idea. At least when it comes to your taste buds. The unaged spirit doesn't require a still, so early illicit versions were cheap, easy, and plentiful. During London's 18th-century gin craze more than 7,000 dram shops dispensed an adulterated concoction appropriately known as Mother's Ruin. In America, Prohibition's "bathtub gin" was often made with barely palatable industrial alcohol.

TIP!

The Alcohol and Tobacco Tax and Trade Bureau defines gin as an unaged spirit, so you won't find a gin label that says "Barrel Aged." Instead look for "Barrel Rested" or "Barrel Finished."

lines that squiggle out across the grain, creating a particularly watertight wood. White oak, when toasted, has a high concentration of lactones, molecules that impart bourbon's unique woody coconut flavor. The charred barrels can be used only once for the maturation of bourbon because the spirit rinses the color and flavor out of the wood, with every batch exhibiting less barrel influence, like a copy of a copy. While that aging process won't work for a second batch of bourbon, it will work for finishing gin with a little bourbon personality.

Gin's predominant flavor comes from the juniper berry, which itself comes from evergreen trees, which accounts for the piney taste. How the juniper is expressed changes with the distiller's mix of fine-tuning botanicals and, now, the nature of the bourbon barrel and the amount of time the liquor is given to rest. Here are the creation stories behind two of our favorite brown gins.



1 Philadelphia Distilling Bluecoat Barrel Reserve

"After experimenting with various capacities, we got the best taste from the traditional 53-gallon barrel, and we rest the spirit two to eight months depending on the season, with faster extraction from the wood during the summer due to the heat and humidity. We actually use new white-oak barrels—new so that they haven't had their flavors extracted and don't retain any flavor profile from a previously aged spirit; white oak because of the element of sweetness that it brings. Most bourbon barrels are a No. 5 char. We prefer No. 3 char, a slightly shorter (roughly 15 seconds) but just as intense

torching process, which gives us a lighter profile of the same flavors we associate with bourbons—vanilla, caramel, nut."

—ANDREW AUWERDA, COFOUNDER

2 Watershed Distillery Bourbon Barrel Gin

"We took a trip to Louisville, Kentucky, and bought three bourbon barrels—previously used for Maker's Mark and Wild Turkey. When we got them back to Columbus, Ohio, and knocked out the bung (the stopper), there was still bourbon sloshing around inside. We added our Four Peel Gin, a nontraditional—some would say 'American'—gin with the juniper played down and the citrus played up. But after 45 days, we didn't taste

↑
Thieving (or sampling) gin from a resting bourbon barrel at Philadelphia Distilling.

much of a difference, so we pushed the barrels into the corner and forgot about them. When we tried the gin again nine months later, the spirit was changing, and when it hit a year, we said, That's it. That's delicious. The barrel finishing mellows out the grapefruit, fuses the warm botanicals like allspice, cinnamon, and coriander, and bestows a rich but subtle amber color. We're not supersophisticated about the timing process—we let it go for anywhere between 11 and 13 months—because we like a little variation from batch to batch. We still want it to taste like gin. But with a touch of bourbon."

—GREG LEHMAN, COFOUNDER





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THE JIMI HENDRIX STRATOCASTER

Backward. Awesome. And now you can buy it.

The world isn't fair to lefties, even when they're rock gods. Jimi Hendrix had a hard time finding left-handed guitars, so he flipped over and restrung standard right-handed Fender Stratocasters. That changed the string tension and microphone location and produced Hendrix's signature mix of bright highs and delicate lows. This month Fender is releasing a Jimi Hendrix Stratocaster (for \$900) that will mimic the legend's modifications. Here's how it works. —KEVIN DUPZYK

STANDARD STRATOCASTER

Fender's **headstock design** makes every string a different length, so restringing the guitar upside down changed which strings were longest. This altered the subtle overtones produced by vibrations on the unplayed part of the string above the top of the neck, near the tuning keys.

On a traditional Strat, the **highest strings** (E, B) are longest. Upside down they become the shortest, so they don't have to be pulled as tight to be in tune. For Hendrix that made them easier to bend, crucial for songs like "All Along the Watchtower."

For the same reason, Hendrix's **low strings** were comparatively tighter, which made them sound less booming and twangy.

Guitar **pickups** are like a set of mini-microphones, with a pole magnet aligned below each string. The distance between the magnet and the string varies for each string. By reversing the orientation of the traditional Stratocaster, Hendrix changed which strings were closest to their magnets and, consequently, most prominent in the mix.

The **rear pickup** on the traditional Stratocaster is slanted to capture the higher strings near their base, where they have a more piercing tone. On Hendrix's guitar it catches the higher strings farther up, so instead of shrieking, they sing.

JIMI HENDRIX STRATOCASTER

NEW!

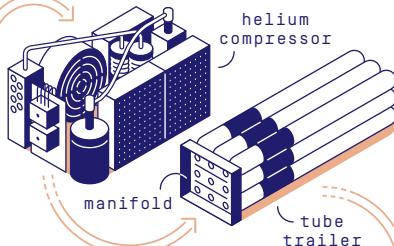
POPULAR MECHANICS EXPLAINER

How do parade organizers get 700,000 cubic feet of helium to New York City for the balloons in the Macy's Thanksgiving Day Parade?

STEP 1: STORAGE
Workers at an industrial gas facility in Bethlehem, Pennsylvania, store a mix of gaseous and liquid helium in large cryovessels, which have five layers of antimagnetized steel or aluminum. Liquid nitrogen between the

outermost layers and an airtight vacuum between the rest maintain the helium at or near minus 452.2 degrees Fahrenheit. Over time more of the liquid helium in the tanks turns to gas, but the temperature remains the same.

STEP 2: COMPRESSION
A few days before the parade, workers connect a cryovessel to a helium compressor. A piston in the compressor then creates suction, pulling the gaseous helium into a compression chamber

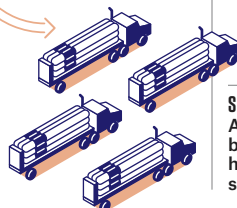


through a hinged flap. As the flap closes, the piston reverses, compressing the gas and opening a second hinged flap that rushes now-compressed—but still gaseous—helium through a manifold and into a large tube trailer,

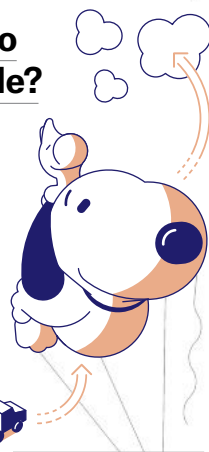
of up to 180,000 cubic feet, for transport.

STEP 3: DELIVERY
Four tube trailers filled to 3,000 pounds per square inch roll into Manhattan the day before Thanksgiving. Dozens of volunteers

fill each four-story-tall balloon through a hose that attaches to the tubes on the trucks. The compressed helium's intense pressure would rush out too fast for workers to control, but a pressure-reducing valve limits flow to a safe 50 psi.



STEP 4: DISPOSAL
After the parade the balloons vent the helium into the atmosphere. —MATT JANCER



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FABRIC

THE HANDS BEHIND A PERFECT PAIR OF JEANS

The pattern-maker is the unsung hero of jean production. Raleigh Denim's happens to be an 81-year-old master. **BY SEAN MANNING**



Despite years of working with denim, Ellsberg herself doesn't wear jeans. It's cheaper and requires less yardage to make her own skirts.

But the jeans couldn't ever become jeans were it not for Christel Ellsberg, Raleigh Denim's 81-year-old pattern-maker.

The importance of pattern-makers within the fashion industry is often overlooked. The designer receives all the fanfare, but it's the pattern-maker who creates the minutely calibrated stencils around which fabric is cut—thus translating the designer's visions into actual wearable garments. Practically every modern pattern-maker relies on computer-aided design. Not Ellsberg.

From inside the small design room sequestered from the rest of the factory floor, she uses little more than a pencil, a ruler, a tape measure, and scissors—the same as she has for six decades.

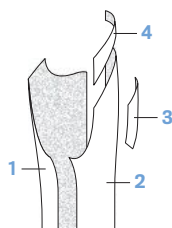
After Soviet troops invaded her East Prussia hometown at the end of World War II, Ellsberg fled with her family to Berlin. There she began apprenticing as a tailor. “My grandmother said, ‘Learn how to sew and you will always have a job,’” Ellsberg recalls. At age 20 she emigrated to Canada and, despite not speaking English, did piecework in a Toronto factory. Ellsberg later attended pattern-making school, where she learned grading, draping, and drafting—skills that largely left the U.S. as production moved overseas. It was also in the pre-email era of the '60s that she sent a handwritten résumé to Levi Strauss & Co., and became only the second pattern-maker in the company's history.

“They weren't as big as they are today,” says Ellsberg. “But they wanted to do more women's jeans, and their thinking was that a woman should make them.” Ellsberg spent 12 years at Levi's, producing the silhouettes that would help turn the American work-wear company into an international fashion brand, and 20 more at other denim companies, most recently one outside Raleigh. She was laid off in 2008 when the sour economy hit the apparel industry hard, and wound up taking a sales position at Jo-Ann Fabric and Craft, a master of her trade reduced to hawking swatches to hobbyists. Then one afternoon her hairdresser mentioned an article in the local paper about nascent Raleigh Denim. The next day Ellsberg went to Lytvinenko and Yarborough, who'd recently expanded to a work space outside their apartment.

“I was like, we would love to work with you but we can't really afford to hire anybody,” recalls Lytvinenko. “She said, ‘That's fine. I'll work for free until you can pay me.’”

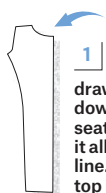
Ellsberg's antediluvian method is difficult—calculating and cutting by hand each paper pattern, one for every style and size, requires several hours of painstaking concentration. But it ultimately yields a superior jean with a customized fit since she's able to make pattern adjustments for denim type and shrinkage rate. “I think I'm the last of my kind,” she says. And her hard-earned skills make the jeans complete originals.

Ellsberg's antediluvian method is difficult—calculating and cutting by hand each paper pattern, one for every style and size, requires several hours of painstaking concentration. But it ultimately yields a superior jean with a customized fit since she's able to make pattern adjustments for denim type and shrinkage rate. “I think I'm the last of my kind,” she says. And her hard-earned skills make the jeans complete originals.

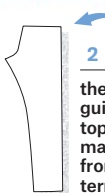


Your Jeans, in Pieces

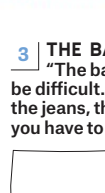
The critical components that make for great-fitting jeans, according to pattern-maker Christel Ellsberg.



1 THE FRONT Ellsberg starts by drawing a straight line down the center. “The seat, inseam, curves—it all comes from that line.” The cutaway up top is the pocket.



2 THE BACK The backside of the jeans as distinguished by the intact top. Both legs are made from the same front and back patterns, just flipped.



3 THE BACK POCKET “The back pocket can be difficult. The smaller the jeans, the less room you have to work with.”



4 THE YOKE The small left and right pieces just above the back pockets. “A curved yoke, especially on women, makes for a better fit around the waist.”

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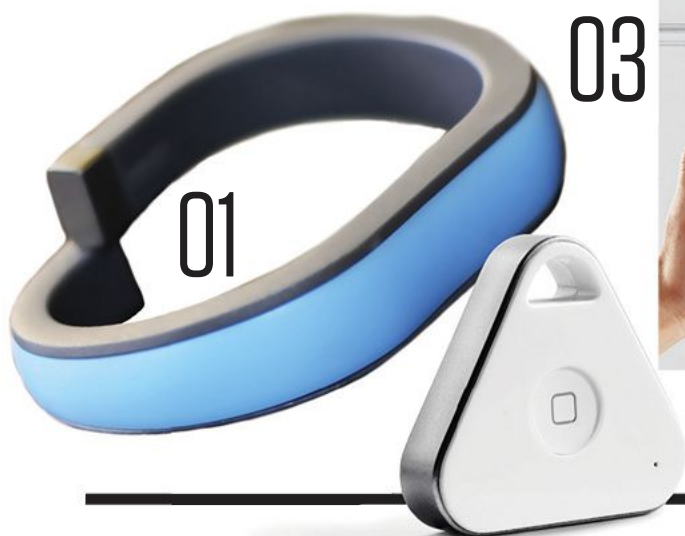
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02



03



04

01

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Q



How often do ambulances and fire trucks cause accidents on their way to emergencies?

A PRETTY OFTEN. THOUGH, in fairness, nobody tracks how many accidents involving emergency vehicles were actually *caused* by them, and, frankly, mishaps involving any motor vehicle are alarmingly common. You're probably at least as safe in an ambulance as you are in an ice cream truck—especially if you're having a heart attack induced by one too many Choco Tacos.

Here are some stats: According to data presented in 2014 by the National Highway Traffic Safety Administration, ambulances were involved in an average of 4,500 crashes a year between 1992 and 2011. Of these, an average of 29 resulted in fatalities, while 1,500 caused injury. At the risk of descending deep into eye-glaze territory, we should add now that a little over half of both the fatal accidents and the injury-causing accidents occurred while the ambulance was in emergency use. Boiling all this down, you discover that ambulances in emergency use account, on average, for 17 fatal accidents a year. Consider that in 2013 alone there were a total of 30,057 fatal crashes in the United States (or more than 82 per day) and the record for rushing ambulances doesn't look out of line. Similarly, fire trucks are routinely involved in accidents while responding to emergencies, but, data shows, they account for far fewer wrecks than do taxis, school buses, or cop cars. All in all, it's a safe bet that emergency vehicles save far more lives than they cost. The real question

is how many people get run over by bookmobiles while walking to the library.



How high is the elevated level of radiation you're exposed to on a plane? Do pilots have a greater cancer risk?

There's no question that flying on passenger jets exposes you to elevated levels of a lot of things, including arbitrary fees, other people's elbows, and assorted noxious and costly substances putatively classified as "snacks." Anything else you're subjected to is arguably mild in comparison. But, yes, you are hit with extra radiation up there in that fancy aluminum tube.

At ground level the atmosphere shelters us, but 6 miles up, levels of the rather groovy-sounding "galactic cosmic radiation" are much higher. "It comes from deep in the galaxy," explains Jeri Anderson, a health physicist at the National Institute for Occupational Safety and Health. "It's caused by the remnants of a supernova." Whoa. Shields up, Mr. Sulu!

Just living your life, you're apt to soak up between 1 and 5 millisieverts (the metric measure of radiation energy absorbed by the body) each year. This comprises radiation emitted by the earth itself, radon gas wafting around your man cave, your glow-in-the-dark watch dial, X-rays of your sprained pinkie toe, etc. Incremental exposure for airline crews is estimated at an

additional 2 to 3 millisieverts. So not that much, really.

Ideally, we'd all limit our annual exposure to 1 millisievert, though that's not easy to do absent a lead jumpsuit, and experts say levels above that aren't necessarily dangerous. Even so, there is some indication that those who work on airplanes (and presumably those who fly several times a week) face increased cancer risk. A 2014 study, for instance, found that the melanoma (skin cancer) death rate is 42 percent higher in airline crews than in the general population, while other research has suggested a heightened breast cancer risk. But it's hard to say that radiation is the sole—or even primary—cause. For one thing, flight crews tend to suffer from disrupted circadian rhythms (a.k.a. jet lag), which can lead to hormonal imbalances that also have detrimental health effects. And anyway, that's flight crews. The rest of us probably have more to fear from overzealous pat-downs in the security line. Unless you like that sort of thing.



How many operating garbage trucks are there in the United States?

Just enough to wake up every man jack from Kauai to Key West at 5:30 in the morning on whatever day of the week he finds himself least inclined to be woken up at 5:30 in the morning.

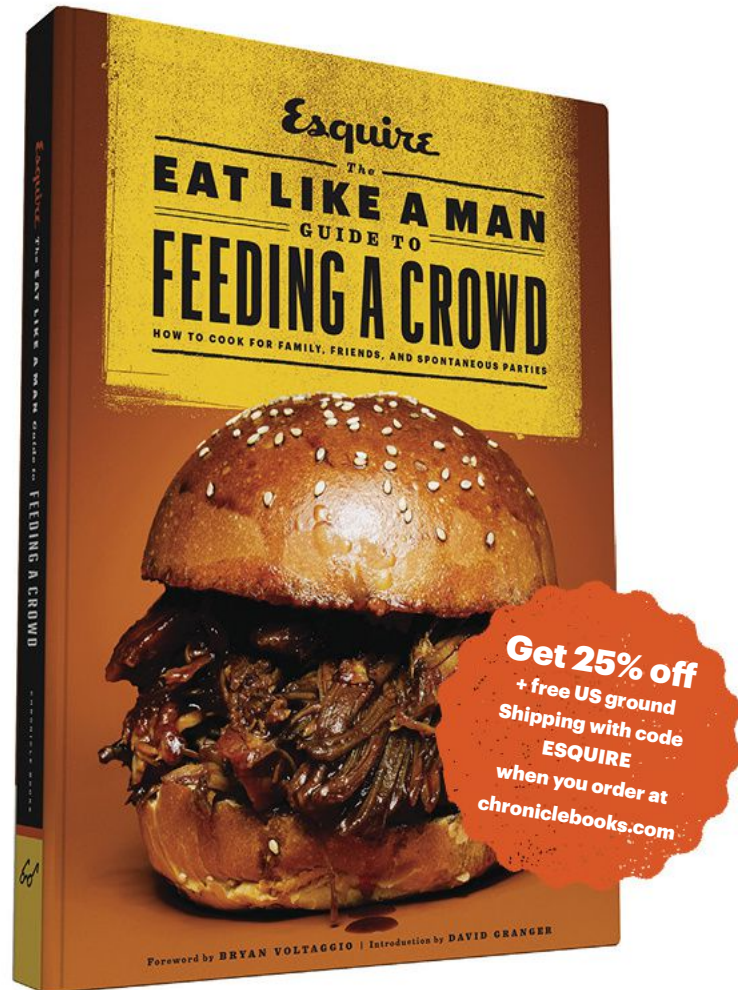
Yes, you say. But how many is that in, you know, numbers? Turns out nobody knows for sure.

The two top waste-disposal companies—Waste Management and Republic Services—together operate about 48,600 trucks. But, though those two giants control a hefty chunk of the market, there are a whopping 27,000 other solid-waste-disposal companies in the country, each of which you figure has to have at least one truck, and in many cases a bunch more. So even at an average of, let's say, four trucks, which may well be low, you're north of 150,000 total.

To take another tack, the National Waste & Recycling Association tallied the number of trucks nationwide at 148,000—but that was in 2001. Industry revenue has grown 46 percent since then, which does not necessarily mean there are now 46 percent more trucks, but does suggest some increase. All things considered, we think a reasonable estimate would put the total number of garbage trucks somewhere within clattering-can-throwing distance of 200,000. Sweet dreams.

The only cookbook you'll ever need when the party is at your place!

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SKILLS



THE MOST USEFUL TOOLS IN YOUR KITCHEN

You may not keep them in the toolbox (in fact, you probably shouldn't), but kitchen knives are just as functional and important to understand as a hammer. Sharper too.

BY FRANCINE MAROUKIAN

Although there are as many design variations as there are brands, kitchen knives fall into two general categories, western (typically German) and eastern (traditionally Japanese). Their functional differences are based in the regional kitchen cultures they grew from.

Western knives are hefty in order to meet the demands of

classic European cooking, in which the staccato motion of chopping, dicing, and mincing brings the blade edge in constant contact with the cutting board. These knives usually have “softer” blades—reflected in a lower HRC, or hardness measured on the Rockwell C scale (see page 38)—that are easier to sharpen but less likely to hold an edge. Eastern knives are

lighter with a sharper cutting edge required to perform the delicate precision of Southeast Asian techniques. Their blades typically use a harder steel alloy that holds that sharper edge, but the edge is more brittle, requiring greater care in handling and maintenance.

Along with HRC, you also want to know what your blade is made of. Basic steel is a mix of carbon and iron, but adding elements creates alloys that are harder or more resistant to corrosion. High-carbon stainless steel does not rust, allows the blade to keep an edge, and gives it a better tensile strength—the amount of stress you can put on the cutting edge before it fails. You'll find varying degrees of elements such as nickel, vanadium, molybdenum, and manganese. (Specific formulas are often stamped on better blades. See below right.) Each has its own influence on edge-holding properties and corrosion resistance.

A LESSON IN HRC

HRC indicates a metal's resistance to force. The number is determined by pressing a penetrator such as a diamond cone into the material, then measuring the resulting deformation or depth of indentation. The standard HRC for better-made German kitchen knives is 56 to 58 with some Japanese knives going up to 62.



A VISUAL GUIDE TO CUTTING EDGES



► **V-SHAPED**
Both sides slant straight down to form the cutting edge.



► **BEVELED**
Makes the blade more durable while keeping the cutting edge thinner and easier to sharpen.



► **CHISEL**
Only one side of the blade is sharpened, typical in Japanese knives used with a gliding motion.



► **SERRATED**
A notched blade that is pulled across (rather than pushed down) what you are trying to cut.

THE ANATOMY OF A KNIFE

1 POINT

For piercing, like cutting slits in a roast to insert garlic cloves.

2 TIP

For more delicate cutting work and as an anchor during mincing.

3 HEEL

Where the blade is thickest. Used when more force is required, like when you're cutting through

butternut squash or a small bone.

4 BOLSTER

This "collar" protects your fingers from the end of the blade when you hold the knife. It also moves the center of gravity toward the handle, so it's better for high-impact jobs. Classic Japanese knives, especially those used for raw

fish, have no bolster, allowing full use of the blade.

5 HANDLE

Most western chef's knives have a contoured handle, but there are plenty of variations. The shape you prefer will depend on your grip. Traditionally made for smaller hands, Japanese knives often have an octago-

nal, round, or D-shaped handle.

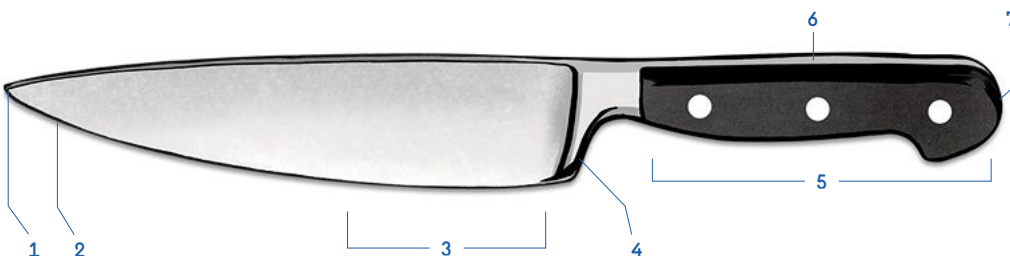
6 TANG

At one time a full tang, or the visible line of metal continuing back from the blade through the two handle slabs, was the sign of a good knife. It makes the handle feel connected to the blade. In lighter knives, especially of Japanese design,

the tang can be shaped like a "rat tail" and inserted half or two-thirds of the way into an enclosed handle.

7 BUTT

The most durable part of the knife. If you're desperate (and don't love your knife as much as you should), the butt can be used to pop open a can. Not advocating, just saying.



HOW TO READ YOUR KNIVES

Two examples:

X50 CrMoV15

(PRIMARILY GERMAN KNIVES)

The X=stainless steel. The 50=0.5 percent carbon for sharpness. The 15=15 percent chromium for stain resistance. Molybdenum (Mo) and vanadium (V) enhance stain-resistant properties, hardness, and edge retention.

VG10

(PRIMARILY JAPANESE KNIVES)

The "G" is for gold standard. At 1 percent, these knives have more carbon than X50 CrMoV15, so they'll take an edge better. They also have the same 15 percent chromium for stain resistance. The more common variant, VG1, isn't as durable. Or expensive.



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HOW TO BUY KNIVES

By chef Charlie Palmer



Equipping your kitchen doesn't mean buying a presorted set that includes knives you may never use. It's more practical to invest knife-by-knife, in this order, as your skills and interests develop.

THE CORE COLLECTION

1

Chef's knife



The classic European chef's knife has a curved, rigid blade designed for a rocking motion, often employing the tip as a stationary pivot. Always used on a cutting board, the tall blade provides maximum knuckle clearance. An 8-inch blade is standard, but chef's knives are available from 6 to 14 inches. (The measurement doesn't include the handle.)



You hold a chef's knife differently than you would a pocketknife. For chopping, the preferred "claw grip" involves pinching the blade between your thumb and forefinger just ahead of the bolster while the rest of your fingers wrap around the handle and out of the way. This provides balance and lets your knuckles guide the blade.

2

Offset serrated knife



An offset handle keeps your hand above the blade, providing leverage and knuckle room for cutting through crusty baguettes and tough-skinned fruits like oranges. Look for a scalloped edge cut on one side instead of jagged saw teeth. That way you can also use this knife to cut delicate things such as tomatoes and soft cheeses.

3

Paring knife or 6-inch utility knife



A lot of people swear by their paring knives, small blades with tapered tips used for precise hand-held work. You could do that, or you could use what I do: a midsize Japanese utility blade (pictured). It fulfills most paring-knife tasks but will also handle light slicing jobs and can even be pressed into service as a filleting or boning knife.

SPECIALTY KNIVES

4

Flexible 6-inch boning knife



Used to remove bones from raw meat and poultry. The pointed tip and flexible blade can maneuver around the contours of joints and also remove silver skin (connective tissue) and fat.

5

8-inch carving knife



Best for bone-in meat and big birds like your Thanksgiving turkey. The narrow, slightly flexible blade is long enough to work big pieces of meat, and the sharp tip handles the curves around bones. Get a carving fork too. It keeps the meat in one place.



STUPID OR AMAZING?

THE EDGE PRO KNIFE SHARPENER

We asked Ben Dale, inventor of this crazy-looking sharpener that holds the knife at a precise angle to produce a sharp blade without damaging the cutting edge, to explain why the Edge Pro is better than a whetstone or a steel, and why it's worth \$165.

No one really sharpens a knife with a steel, those metal rods you see people running the blades of their knives up and down on. All it does is rip some fragments of metal loose on the edge. These fragments are sharp, so they allow the knife to cut better, but only for about 20 minutes, at which point you need to steel again because the fragments have broken off into your cutting board and your food. Each time you use the steel, the edge of the blade gets rounder, and soon you are not able to get any steel to break loose. Then the knife is dead. A whetstone is better, but it's still tricky. It is almost impossible for human hands to make a consistent enough stroke, holding the blade at the precise angle along the grinding surface to get a really good edge. I am as good as you can get, and I still have about 2 degrees of variation in my stroke. Every little bit you're off takes away from the sharpness and increases the chance you'll damage the cutting edge.

VERDICT



STORAGE

Wooden blocks are unsanitary, trapping microscopic bits of food. Plus the block can damage blades, which are inserted with the vulnerable cutting side down. I keep my knives where I can see them, on a wall-mounted magnetic bar.

CUTTING

Never cut on ceramic, glass, or marble. It will damage your knives and dull the cutting edge. Use wood, bamboo, and wood-fiber composites—materials with a little more give. —C.P.



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PRO-DUTY CHAINSAWS

A little more expensive than entry-level saws. A lot more powerful. **BY RICHARD ROMANSKI**

We're no strangers to evaluating chainsaws here at Popular Mechanics, but this year's test of pro-duty saws was difficult to call. These machines are that good. We sawed test discs and timed the cuts. We cut firewood. We started the saws cold and we started them warm. Start, cut, stop, repeat. We even judged the owner's manuals. After all that sawing and plenty of discussion, analysis, and even a little knuckle chewing, a winner finally—and barely—emerged.



ENGINE SIZE:
50.1 cc



HUSQVARNA 550 XP
\$600

Engine weight: 10.8 lb

Likes: A lightning-fast saw with great throttle response and plentiful torque. We liked the way the gas and bar-oil caps had fold-up

handles that stayed out of the way until needed and were easy to use with gloves on. And with a side-mount chain-adjustment screw, it's fast to service.

Dislikes: When the saw is warm, a quirky restart procedure can cause you to flood it.



ENGINE SIZE:
50.1 cc



JONSERED CS 2253
\$565

Engine weight: 11 lb

Likes: A great saw and, as far as we can tell, a red version of the Husqvarna at a slightly lower price.

It was about as fast as its doppelgänger but had just a bit more vibration—not enough to worry about, but noticeable on the toughest cuts.

Dislikes: Difficult to start warm.

**BEST
OVERALL**



ENGINE SIZE:
50.5 cc



STIHL MS 261 C-M
\$600

Engine weight: 11.5 lb
Likes: The Stihl might be a pound heavier and an inch longer than the competition, but it's a good, torque-rich saw that bites in and stays with the cut, no matter how tough it gets. Part of the reason for that is the saw makes its full horsepower (3.9 hp) at a couple hundred lower rpm than the other saws, so it's not working as hard.
Dislikes: None.



ENGINE SIZE:
50.2 cc

★★★★☆
ECHO CS-500P
\$460

Engine weight: 10.6 lb
Likes: A lot of saw for the money. It's easy to start and all but impossible to flood, whether cold or

warm. We appreciate the traditional adjustable carburetor and the toggle switch for on and off.
Dislikes: Could definitely use captive bar nuts. The only saw not to have them.



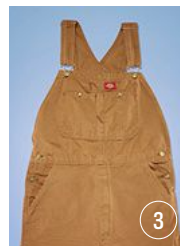
1

OVERALLS

The best way to stay clean and comfortable while you work. Now with even more pockets.



2



3



1. CARHARTT R28 \$75

Super-durable—as much riveted together as sewn. Double-thick knees and an attached four-pocket nail apron. Warm. Elastic suspenders made these more comfortable than the others.



2. POINTER BRAND LOT 333 \$52

Full-cut for comfort and breathability. Has a smart zippered chest pocket so items don't fall out when you bend over. The only tested option made in the U.S.



3. DICKIES DB100 \$32

Surprisingly supple. Comfortable. Lack of rivets made up for with plentiful bar-tack stitching at stress points.

WHITE BIBS: A EULOGY

► As a teenager working construction in 1977, I noticed a shift in carpenter culture. Some of the old guys, and no one else, wore baggy white bibs with an attached nail apron—a style that even then was a vestige of the past. One rainy day my boss took me to meet one of them. "The best carpenter there is," he said. That man, along with his pants, became my image of the ideal. Now white bibs are all but gone, occasionally replaced by nail bags, gym shorts, and running shoes. Although clothes have no influence on the quality of a person's work, nothing will ever have the same history. Or impact.

—ROY BERENDSOHN

TROUBLE LIGHTS

Versatile new takes on a classic. Because you can't work on what you can't see.

BEST OVERALL

★★★★★

1. MIGHT-D-LIGHT RECHARGEABLE LED STICK LIGHT \$12

Lumens: 175
Lightweight. Hangs from a slide-out hook or two magnets. It also has a rotating-head flashlight, a belt clip, and a bottle opener. All for a quarter the price of the competition.

★★★★☆

2. TORCHSTAR RECHARGEABLE LED WORK LIGHT \$40

Lumens: 280
Useful pivot adjusts the beam without moving the light. We really liked the high-strength magnet in its base. It's powerful enough to hold the light right-side up, upside down, or out sideways.

★★★★☆

3. CRAFTSMAN 73994 \$40

Lumens: 200
Packed with features, including a secondary flashlight with a rotating head. A cleverly concealed hook slides out of the base to hang the light from a nail or piece of lumber. Two strong magnets at the top and bottom hold the light to metal.

★★★★☆

4. MILWAUKEE 2363-20 M18 LANTERN/FLOOD LIGHT \$80 (light only)

Lumens: 700
A beautifully made and well-engineered industrial-duty light with three settings, from 70 to 700 lumens. Its sturdy stainless-steel hanging hooks would keep it suspended in a hurricane.

★★★★☆

5. CAPRI TOOLS CP40464 \$44

Lumens: 300
A rubber coating adds grip and durability, and its detachable side magnet is strong enough to support the light from a metal surface. The magnet can be positioned at various places on the body.

★★★★☆

6. BAYCO PRODUCTS NIGHTSTICK NSR-2166R \$40

Lumens: 230
A detachable magnetic hook allows the light to hang from the top or the side. (The magnet is strong enough only to mount the hook, not to hold the light to a metal surface.) Also works as a flashlight.

Traditional cage lights like this one can get very hot, a problem LEDs don't have.





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ELECTROCARDIOGRAPH

MODEL: GE MAC 2000

NUMBER OF PARTS:

281

PRODUCED:
BANGALORE,
INDIA

TIME TO
DISASSEMBLE:
5 HOURS,
21 MINUTES

NOTES: Muscles are machines, powered by electricity. An electrocardiograph is a multimeter of the heart, with ten lead wires instead of two. As your heart beats, electrodes on the lead wires pick up the resulting electrical signals from strategic points on your body. These signals are interpreted in three dimensions by a cardiologist—who can literally see your heartbeat.

TURNING IT ON

The MAC 2000 is designed to be adaptable to a variety of hospital environments. Its **power supply (16)** can work with wall power from a cord through the **power inlet (12)** or electricity from the onboard 14.4-volt lithium-ion **battery (13)**, which is designed to power the machine for three hours.

Because hospitals

have different systems for organizing patient information, the **rear-connector-panel cover plate (1)** includes ports for connecting Ethernet and flash-memory cards and a bar-code scanner. Or there's always the **keyboard (3)**.

PREPPING THE PATIENT

The electrocardiograph uses electrodes to detect the 1- to 2-milli-

volt electrical signals that make the heart contract. While some countries use reusable electrodes, disposable electrodes are more common in the U.S. To accommodate both, the MAC 2000 uses

lead-wire adapters. One end of the **electrode adapter clip (6)** grips the electrode and the other latches onto a **lead-wire adapter (7)**. Six electrodes are grouped around the heart and one is placed on each limb, capturing the electricity of the heartbeat in two planes: one parallel to the waist and one perpendicular. An electrolyte gel transmits electricity from the skin to silver plating on the electrodes. The electricity then makes its way up the network of **lead wires (8)** through the main wire, or **patient cable (14)**, and into the electrocardiograph.

THE EXAMINATION

The real job of the electrocardiograph is to translate the heart's electrical signals into waveforms a cardiologist can interpret to detect problems. That means doing some math with the signals. When they first enter the guts of the machine, those signals are too weak to work with, so they are sent through an **instrumentation amplifier (4)** to boost them from millivolts to volts and then through a **band-pass filter (4)** to remove high and low frequencies, isolating the useful midrange. An **analog-to-digital converter (5)** turns the

stronger, clearer signal into a digital value.

While these digital values are generated by the electrical impulses measured by the ten lead wires, they are used to calculate 12 different leads. Each lead is a calculation of the electrical potential between electrodes, which changes when the heart contracts. Tracking this potential in voltage over time produces waveforms, which are displayed in a 3 x 4 grid on the machine's 7-inch **LCD display (2)**.

DIAGNOSIS

Doctors see information from the 12 leads in a report called an electrocardiogram, or EKG. The MAC 2000 prints the report on demand with a printer. Its **thermal printhead (11)** carries a straight-line array of heater elements, each of which prints when a corresponding transistor is activated. The **thermal paper (15)** used by the printer has a 1-mm grid. The standard scale for an electrocardiogram is 10 mm per millivolt and 25 mm per second, but that can be adjusted. To accommodate this, the printhead and a small **motor (9)** that drives the **paper roller (10)** are electronically controlled to produce the scale the doctor selects.

—KEVIN DUPZYK

A BRIEF GUIDE TO EKG READOUTS





WELCOME HOME THE BRAVE

A black silhouette of a soldier in full combat gear, including a helmet and a rifle, walking towards the right. The soldier is positioned within the letter 'A' of the word 'BRAVE' in the main title.

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At Stew's, you can rent bays by the hour or pay \$320 for a full 12-hour day. And if you just want to change your oil? Fifteen bucks for 30 minutes.



THE DIY AUTO SHOP

Welcome to Stew's Garage, the auto-mechanic shop that's equipped with everything but the auto mechanic. That would be you. **BY LIANE YVKOFF**

Washington state during the winter is no place to work outside on your car. But that's exactly what 21-year-old Stew Waliser had to do two years ago, when he was a broke Central Washington University freshman and needed to repair the suspension on his Toyota Tacoma. Lying on the miserable, hard ground, his head in the snow, a cold wind whipping up his pant legs, Waliser envisioned a warm garage where people could drive in and work on their cars—tools lining the walls, lifts, coffee percolating in a machine in the corner, maybe a radio playing. Local folk would come and go, helping each other out. A

community. That would be nice. So he built one.

Waliser dropped out of college and opened Stew's Garage, a self-service repair shop that anyone can pay to use. Forty dollars an hour gets you a bay equipped with either a two- or four-post lift, a dedicated 450-piece tool set, even recycling and waste disposal. And, if you need advice, Stew's has that too. (Insurance prevents Waliser or his employees from physically assisting with repairs, but they can and will give you as much guidance as you want.) Customers also have free use of compression tools and heavy equipment, including a bench grinder, a shop press, engine hoists, and a wheel balancer. There's even a place for

people to give back to the Stew's community, donating things they don't need—a slush pile of excess motor oil and transmission fluid, spare parts, and a turbocharger from a 2.7-liter Audi engine. All up for grabs.

"The point behind this shop is that it's everybody's," Waliser says. His customer base includes pizza-delivery drivers and men who wear suits to work. On warm evenings Waliser sometimes drags his worn fire pit out into the parking lot while someone runs out for hot dogs and buns. The garage is open until 9 p.m. Customers, staffers, and friends sit on folding chairs and roast their dinner, swapping advice and stories.

A community. It's nice.



HOW TO KEEP TRACK OF YOUR TOOLS

A new app called Share My Toolbox (available now for Apple, early 2016 on Android) lets you catalog every hammer, jigsaw, and nail gun in your collection. (A subscription-based version that offers even more features for businesses launches in December.) Friends can download it, add their own tools, and request to borrow any of yours, which are automatically tracked by the app. You can set your own loan periods and terms. The app will even bug borrowers when it's time for something to be returned. It's a great way to expand your workshop without spending any money. And a terrible way to try to make off with your neighbor's new band saw.

GET YOUR HANDS DIRTY AT THESE DIY GARAGES

1 Stew's Self Service Garage
Kirkland, Wash.

2 Pit Row
Santa Clara, Calif.

3 Your Dream Garage
Baldwin Park, Calif.

4 DIY Auto
Westminster, Colo.

5 DIY Auto Garage
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Popular Mechanics' senior home editor solves your most pressing problems.

BY ROY BERENDSOHN



The crack in our upstairs hallway comes back no matter how many times I patch it. What's the right fix?

ALFRED P., MORRISVILLE, PENNSYLVANIA

A Seasonal cracks in drywall and plaster are tough to repair. As they open and close, one of two things happens: The surface around the crack crushes and grinds the patch material or it pulls it apart, ripping the material away from the wall or ceiling surface. You need a super-flexible material and one that can bridge a wide gap. I've used **DAP Elastopatch** with good results. The material is about the consistency of yogurt, and you can apply it with a **6-inch joint-taping knife**.

Although it's pretty simple to use, it'll take you a few tries before you can produce a smooth finish. I'd recommend experimenting on a cast-off bit of drywall first.

Before you patch, use a **painter's 5-in-1 tool** to rake out the former repair materials. Then scoop out the patch and spread it on in thin layers. Wipe off any excess (you won't be able to sand it down like joint compound), let the patch dry, then paint.

Q What's the best way to stop my toilet from rocking? I've tightened the bolts

at the base, but it's still happening.

JOHN R., FLINT, MICHIGAN

A This is usually caused by a rotting subfloor. First, shut off water to the toilet and pull it out. If it is the subfloor, you'll have to replace the portion that's rotted, the flooring, the toilet-mounting flange, and the wax ring, which makes the watertight seal between the toilet and the pipe. (If your floor is concrete, you might get off easy and all the toilet will need is a new mounting flange. Otherwise, you might have to cut out a chunk of concrete and install a new closet bend, the cast-iron pipe below the toilet, and a mounting flange.) But let's say this is a minor plumbing skirmish, not all-out war. Suppose you can see no evidence of a leak and if you look up from the basement below you don't see a rotted subfloor—it's unlikely, but you never know. In that case, buy a

three-dollar pack of toilet shims, small plastic wedges that come four to a pack. Loosen the anchor bolts, shim the toilet so it's level, tighten the bolts, cut off the excess part of the shim below the toilet using a hacksaw, then caulk.

Q I have an above-ground oil tank that's 20 to 30 years old. Every so often, it drips. The liquid looks like water but feels a little oily. Is this condensation or a leak?

LEROY L., PITTSFIELD, MASSACHUSETTS

A Chances are pretty good that you've got a slow leak. In fact, given the age of the tank, it's almost certain.

Every fuel-oil tank will have some water and sludge at the bottom. The fuel floats above it, like an oil slick. This water leads to rust that will first form a pinhole, which causes an intermittent leak exactly as you describe, usually on the bottom of the tank's curve, or belly. From there it can turn into a steady leak. A simple way to confirm

this is to place a bowl under the tank and let it catch the drip for a few days. With enough liquid accumulated, you'll probably be able to tell immediately if it's oily water from the bottom of the tank. Some oil companies do tank replacements but there are also firms that specialize in this kind of repair work. They clear the tank of oil, leaving some waste oil, sludge, and water that they dispose of. They replace the tank and sometimes the oil lines leading all the way to the boiler or furnace. The new tank may be a simple single-wall model, a double-wall, or even a tank within a leakproof enclosure. Replacement costs can range anywhere from \$1,500 to \$4,500, depending on the size and the type of replacement you choose. By the way, that price assumes that the company doesn't have to dig up and replace any contaminated soil from the area surrounding the tank. This doesn't often happen with aboveground tanks, but it's possible. And expensive.

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STIFF BRUSHES



- ▶ Best for cutting in, a method of flattening out the bristles of the brush that allows you to create a clean line against a wall or a piece of trim.
- ▶ Carry more paint at one time.
- ▶ Leave a rougher finish than soft brushes, so keep the painted area as small as possible.

SOFT BRUSHES



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CARS



TRACK WORTHY, STREET LEGAL

The Dodge Viper ACR puts other so-called track cars to shame.

Race car for the street” is a misappropriated phrase, applied to everything from Porsche 911 GT3s to your cousin’s Honda Civic with the stickers and the big wing on the trunk. When you hear of some new machine described as a race car, that’s typically just shorthand for a predictable roster of modifications: more power, stickier tires, maybe a few pounds less weight. Fine, but not a race car. You want to see what one of those looks like, take a gander at the 2016 Dodge Viper ACR.

The name stands for American Club Racer, and the premise is that this is a car you could drive to a track and enter in a race without any major modifications. Although that might not be wise, as I imagine each highway expansion joint would feel like a Ronda Rousey jab to the kidneys.

STATS



PRICE
► \$122,490

ENGINE
► 8.4-liter V-10, 645 hp and 600 pound-feet of torque

TRANSMISSION
► Tremec TR6060 six-speed manual

WHEELS
► 295/25/19 front; 355/30/19 rear

WEIGHT WITH EXTREME AERO PACKAGE
► 3,392 pounds

COEFFICIENT OF DRAG
► 0.54

DOWNFORCE AT 150 MPH
► 1,228 pounds





past on the VIR front straight, hitting the kink at about 140 mph, and they look about 2 inches lower than they did standing still back in the pits. That's because they are.

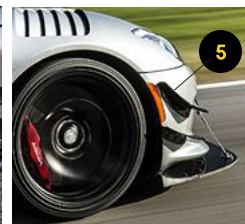
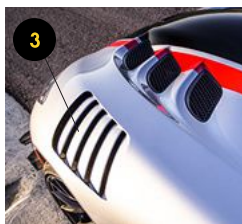
Before we take test laps, the Viper team pairs each driver with an instructor, someone to tell us to cool it if we're retreating too deeply into our Lewis Hamilton delusions. I climb in with a genial fellow named Bernie. The ACR's air conditioning automatically cuts out at full throttle to save horsepower, so Bernie asks if we want to be sweaty with the windows down or sweaty with the windows up. I opt for down, the better to hear the Viper side-pipe-exhaust drama.

Then we hit VIR's 4.1-mile Grand West Course. On slow corners that require pure

I say imagine because Dodge confined the Viper ACR's official launch to the car's more natural element, that contorted ribbon of driving nirvana known as Virginia International Raceway. No expansion joints here. High-speed esses, plunging off-cambers, fifth-gear kinks—it's got all of that.

Letting a bunch of journalists loose on a track with ACRs might seem like asking for disaster, but what Dodge knew is that none of us would crash the car because we'd never test its limits. Say you're in a sustained high-speed corner, pulling a full g. That's around the limit for most high-performance track cars, like Ferraris and Corvettes. In the ACR, though, at 1.0 g you're barely past the halfway point. This car will pull 1.5 g's in sustained cornering. The faster you go, the harder it grips. The average brain cannot comprehend that kind of voodoo.

Aerodynamics is key. Equipped with its Extreme Aero Package, the Viper effectively becomes an upside-down airplane wing, and as the speedometer climbs, the bodywork levers itself ever harder toward the pavement. At the ACR's top speed, 177 mph, the Viper generates 1,710 pounds of downforce. It's like having the Green Bay Packers' offensive line sitting on the roof, crushing the car onto the track. Watch the cars go



AERODYNAMICS

HOW THE VIPER ACR STAYS ON THE ROAD

1. Rear wing

Creates downforce but also drag, helping knock the ACR's top speed down to 177 mph from the standard Viper's 206 mph.

escape, preventing lift. Also, they look ridiculously awesome.

2. Rear diffuser

Adds downforce and aids stability. Designed to be replaceable as you wear it off on the track.

4. Detachable front splitter

A wing to catch wind for the front end. Removable so you don't grind it off pulling into Dunkin' Donuts.

3. Fender vents

Big holes in the fenders allow air to

5. Front dive planes

More wings on the front to even out that huge one on the back.

grip, the Kumho Ecsta V720 tires—developed specifically for this car—let out a low howl as they approach the limit. On fast corners the downforce is so great that the front splitter and rear diffuser grind on the pavement, despite Bilstein coil-over springs that are three times as stiff as those on the standard Viper.

I never quite figure out the braking zones—the carbon-ceramic brakes are so monstrously powerful that even late braking often turns out to be too early. If there's any ill behavior to be found in the ACR, it's that trail braking, or braking as you turn into a corner, elicits some unsettled tail wagging. Perhaps it's because you scrub speed too fast—all those linemen instantly jumping off the roof. I'm sure you could learn how to manage that tendency, even use it to your advantage. That's what a race driver would do. And this, without any caveats or hyperbole, is America's race car.

THIS MONTH IN PECULIAR HOBBIES

HI-RAILS AND SERVICE CARS



I'm driving through Wiscasset, Maine, when I notice a long line of curious little railroad cars stopped on the tracks. They're railroad service cars, now abandoned in favor of modified pickup trucks, called hi-rails. I stop to find out what they're doing back on the tracks, and en

masse. A fellow named Keith Knowlton explains that this is a New England Rail Excursions (NEREX) event, wherein service-car owners get to put them on the rails and go for a drive. Today they're going from Brunswick to Rockland. Knowlton gestures to a silver Ford F-350 and says, "That's

a hi-rail truck. That guy's from Vancouver and he covers 8,000 miles a year—on rails." Today's route is 60 miles, including bridges, trestles, and great views of the craggy Maine coast. I get back in my car and keep heading north, disappointed that I'm confined to the pavement.

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WELCOME TO THE SMASH LAB

At the Insurance Institute for Highway Safety, cars die so that you can live.

The Insurance Institute for Highway Safety in Ruckersville, Virginia, has a history lesson in the lobby. That's where it displays the 1959 Chevrolet Bel Air that it crashed into a 2009 Chevy Malibu to demonstrate the progress in safety over the past 50 years. The Malibu's front end is annihilated, but its passenger compartment looks practically undisturbed. The Bel Air, however, looks like it cruised straight out of one of those gruesome old driver's ed safety videos. Cue the voice-over: "Jimmy was on his way to the prom when he decided to try a little street racing . . ."

Cars are indisputably safer than ever, and that's partly thanks to the work at the IIHS. The organization is funded by insurance companies, so its mandate is to identify problems and then essentially shame the manufacturers into fixing them. I'd always assumed that all cars met federal safety regulations, so they must all be somewhat equal on the safety front. Not so. There's a lot of leeway in the federal standard, a lot of variance between an IIHS Top Safety Pick and a car that wears the dreaded "poor" sticker. Unless you're gonna buy a Volvo and call it a day, pay attention to the IIHS's results.

The IIHS typically buys its own cars to test, which is one reason that its ratings don't include any Lamborghinis or Bentleys. Sometimes, though, a car company volunteers a sacrificial lamb. "Maserati gave us three Ghiblis to test," Becky Mueller, an IIHS senior research engineer, says. "In one afternoon we destroyed about \$200,000 worth of cars." I'm here today because Honda provided the IIHS with a 2016 Pilot for a small overlap frontal test, an extremely brutal type of front-end collision.

In a small overlap crash (as

happens by, say, drifting across the centerline on a two-lane road and clipping an oncoming vehicle), the car's crash structure doesn't have much opportunity to absorb the energy. Absent some clever engineering, the driver's side of the car gets peeled back deep into the passenger compartment. The IIHS began conducting the test in 2012, and it's caused manufacturers to rethink the crash structure in newer models. Honda is betting that the Pilot will dissipate the energy without compromising the passenger cell.

And so here we are at what I like to call the smash lab. There's a barrier, 320,000 pounds of concrete and steel. The lights come up and you feel the heat—the lights are so powerful that they'll incur a \$50 electric bill for the few minutes it'll take to run the test. Hollywood-worthy slow-motion

cameras start rolling. There's a Klaxon and a countdown. The clock reaches zero and the Pilot speeds into the room at precisely 40 mph, pulled by a cable in the floor. Crack! In a matter of milliseconds, the car folds itself around the barrier and bounces off, the sharp sound of impact punctuated by the deeper boom of the left-front tire exploding. The front end is unrecognizable, but the passenger compartment, well, that looks pretty good. The Honda people seem pleased.

IIHS tests are designed to reflect real-world situations, but in one respect the Pilot crash that I witnessed was unrepresentative. In the real world if the car were heading toward a barrier, it would've hit the brakes on its own. It might've also swerved autonomously, thanks to a system called Honda Sensing that initiates emergency braking and steering. The rapid adoption of similar such systems by carmakers has spurred the IIHS to build a whole new outdoor testing facility for safety electronics, portending a day, not far off, when safety depends more on software than steel. After all, the best crash is no crash at all.



THE RECOMMENDATION

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You pay the same price for car insurance whether you drive 100 miles a month or 10,000. For some that's wasted money, like buying a barrel drum of mayo at Costco for just one sandwich. Metromile insurance charges you a flat monthly fee—\$10 to \$100—and one to 50 cents for every mile you drive. And only the miles you drive. Metromile tracks your driving with a free device that plugs into your car's OBD-II port. The service is currently available in California, Oregon, Washington, Virginia, Pennsylvania, and Illinois, with more states on the way.

SEE THE FUTURE THROUGH THE EYES OF THE PAST!

EDITED BY
NEBULA-AWARD
WINNING AUTHOR
**GREGORY
BENFORD**

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2015 BMW X6 M

→ BMW calls the X6 M “the sports car that doesn’t always need a road.” Oops, I’m sorry—that’s what AMC said about the 1981 Eagle SX/4, which likewise paired a coupe roofline with a jacked-up suspension. Those SX/4s are starting to look mighty cool again, perhaps because their shape and purpose are echoed in a contemporary \$103,000 BMW.

Yes, the X6 M is verily expensive, clocking in at about \$23,000 more than a Range Rover Sport Supercharged. It’s also more single-minded than the Rover, forgoing cargo space in the name of style and off-road ability in the name of nobody cares anyway. On-road is where it’s at, and where the X6 M will hound a Corvette from 0 to 60, all while sounding like an Audi Group B car racing a Sopwith Camel biplane. (Its exhaust manifold reorders combustion pulses to keep the turbos spinning, creating a warbling exhaust note unlike any other V-8’s.)

Where BMW is concerned, the two main camps are the purists and the futurists. The purists want every BMW to drive like a 1990 M3, while the futurists celebrate the groundbreaking design of the i3 and i8. The X6 M doesn’t fit into BMW’s past, nor does it seem to exemplify a vision of the future. This is a car for the perplexing present, and the tall-coupe paradigm is popular enough that Mercedes introduced a direct competitor, the GLE. May they both soar like an Eagle.

2016 HYUNDAI TUCSON 1.6T LIMITED

→ Without much fanfare, Hyundai is maturing into a company that wants to be considered on the same terms as its Japanese rivals. At about \$34,000 for a loaded Tucson, this is not a car that you’d buy because it’s less expensive than a Honda CR-V. But you very well might buy it because it’s more fun. Call it the Fyundai. (Or don’t.)

You know how a Ferrari 488 GTB is turbocharged and has a seven-speed dual-clutch transmission? Well, same deal with the Tucson 1.6T! And, okay, 175 horsepower will not have you dreaming of hot laps at Fiorano. But by the standards of the class, rife with drab four-cylinders and droning CVTs, the Tucson is a sports car. The sport mode gives you max torque (195 pound-feet) sooner, and the transmission blips the throttle on downshifts. At stoplights on hills, you want to use the brake instead of creeping ahead with the gas, lest you fry the clutch—warning tags on new cars inform owners to drive like it’s a manual. Imagine that: Hyundai expects its buyers to understand how its transmission works. By small crossover standards, that’s pretty hardcore.

The Tucson looks good (especially with 19-inch wheels), and offers the typical Hyundai raft of equipment. It’s more evidence that Hyundai is moving beyond rock-bottom prices and decade-long warranties and learning the nuanced business of driving pleasure.

2016 VOLVO XC90

→ Here I am in brutal Los Angeles traffic, creeping along in a stop-and-go crawl that stretches over the horizon, and I’m not stressed out. In fact, I’m delighted, because I’ve engaged a function called Pilot Assist that allows the 2016 Volvo XC90 to handle the traffic pretty much on its own. I touch the steering wheel every 15 seconds to assure the car that I’m still conscious, but aside from that the Volvo is on autopilot, radar locked on the car in front of us and a video camera telling the steering to stay within the lane markings. If I lived in L.A., the Volvo XC90 would immediately jump to the top of my shopping list on the strength of that feature alone.

But there’s more to this car than its virtual gridlock chauffeur. The new XC90 is a killer design, inside and out—spare, sleek, understated. The interior is as good as anything from Audi, and later this year the hybrid will become the first seven-seat plug-in SUV (and it’s 400 horsepower too). The optional Bowers & Wilkins stereo has a subwoofer that uses the structure of the car as an enclosure, hitting frequencies as low as 20 hertz—roughly the bottom range for what the human ear can hear. After lunch one day, I showed the Volvo to a trio of 20-something women who wanted to check it out. They were all over it. “I could totally see myself being a soccer mom in this,” said one. “Volvo’s cool,” said another. “Who knew?”

THE FIVE-WORD REVIEW



2015 CHEVROLET SS MANUAL Fast. Rumbles. Bargain. Fun. Discontinued.



2015 AUDI ALLROAD A swanky Outback. Surprisingly nimble.



2016 HYUNDAI ELANTRA GT Noisy, but comfy and inexpensive.

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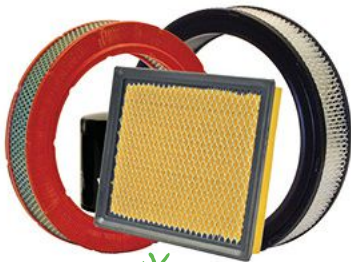
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 **TOYOTA**
Let's Go Places

ROCK CLIMBING

There is immense reward in hauling your own body to the top of a wall using nothing but flexibility, cunning, and the strength of a couple fingers. We asked Sierra Blair-Coyle, a professional climber who buckled into her first harness at age eight, how to get there.

Sierra Blair-Coyle, 21, is a five-time World Cup competitor and a two-time junior National Champion.



Choose Your Discipline

BEFORE YOU CLIMB, you're going to spend a lot of time watching other people climb, so you'd better make sure you like your climbing buddies. In a rock-climbing gym, which is where you should start, you'll encounter two beginner-level disciplines—bouldering and top roping. Most gyms offer both, but some places may have a more robust community around one or the other. The two specialties also tend to attract different kinds of people: Bouldering is great for extroverts and larger groups, and top roping is ideal for those who want to learn with a single friend. It may be worth visiting several gyms until you find a group and style you like.

TYPES OF INDOOR CLIMBING

BASIC



Bouldering, or creeping up, under, and across shorter structures (in a gym, these reach up to 20 feet) like a crab, tends to be more social, because lots of people can climb at once. Bouldering does not require a harness or ropes, but can demand acrobatic moves: It started out as a way for long-distance climbers to practice difficult tricks close to the ground.



Top roping, or creeping up taller walls (indoors, up to 45 feet), is better in pairs. This is the easiest form of long-distance climbing, in which climbers tackle vertical routes using a rope. In this case, a rope threaded through an anchor in the ceiling is tied to your harness. Your partner on the ground, known as a belayer, holds the other end to let you down.

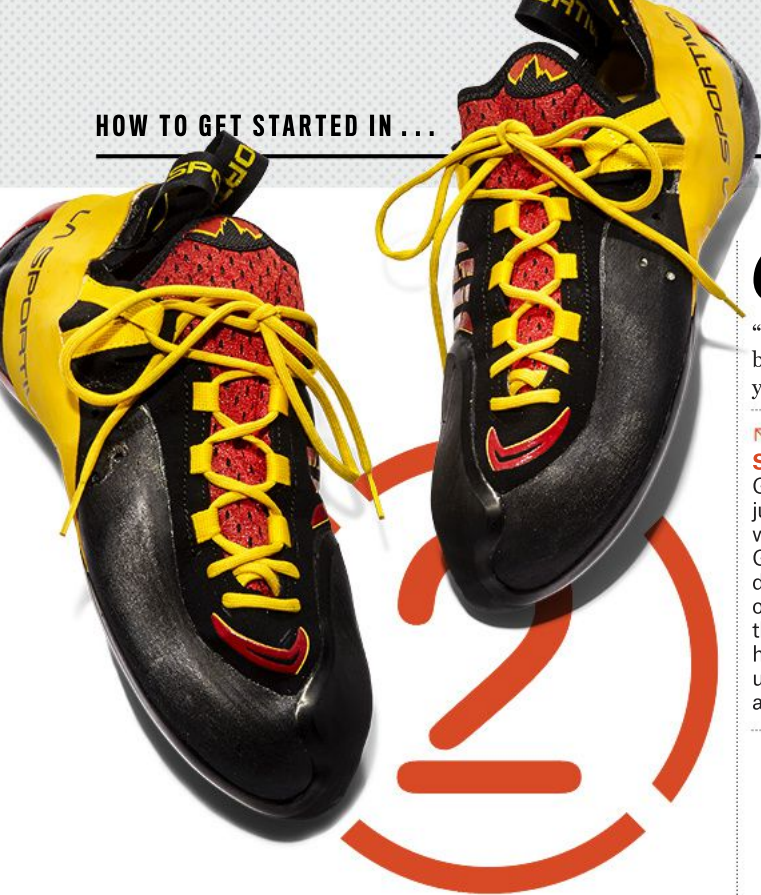
ADVANCED

Lead climbing is a more challenging form of long-distance climbing that can be practiced either in a gym or outdoors. To do it, you tie into a safety rope and then run that rope through anchors set into the wall as you move up it. Outdoors, the lead climber is the guy in the front of the train. Lead climbing also requires a belayer.

Free solo climbing is the same as bouldering, but is performed on walls high enough to cause injury or death if you slip. You—and all the courage you can muster—just climb up a big, scary wall. Solo climbers are the sort who might also enjoy wing-suit gliding or base jumping.*



***A safer alternative:** Want to experience the terror of swinging by your index fingers 1,000 feet up a cliff but don't want to possibly die? Read free solo climber Alex Honnold's new memoir, *Alone on the Wall*, out November 9.



Get Your Gear

"THE FIRST TIME you go to a climbing gym, all you really need to bring with you is yourself," Blair-Coyle says. You can rent everything you need there. Once you're hooked, you'll want these four items.

SHOES

Gripping with your feet is just as important as gripping with your hands. La Sportiva's Genius shoe (\$190) has a gentle downward arc through the arch of the foot—called a downturn—that helps you push on smaller holds. It also has no hard edge under the toes, bringing your actual foot closer to the wall.



CHALK

To get the strongest hold, you need dry hands, and for that you need chalk. FrictionLabs' chunky and fine chalks (\$15 each) contain purer magnesium carbonate than other chalks. Magnesium carbonate is the preferred mineral for sport chalk because it locks up moisture without caking.



CHALK BAG

Chalk bags aren't an area of climbing inclined to innovation, but Organic Climbing's bags (\$22) have a stiff rim to make it easier to dip your hand while you're hanging from a wall. They are also made from recycled materials.



HARNESS

The first few times you try rope-based climbing, you'll spend a lot of time falling into, and hanging around in, your harness. Comfort is important. Black Diamond's Solution Harness (\$70) has triple-weave webbing on the waist belt and leg loops that distributes weight evenly to reduce pressure on hot spots.

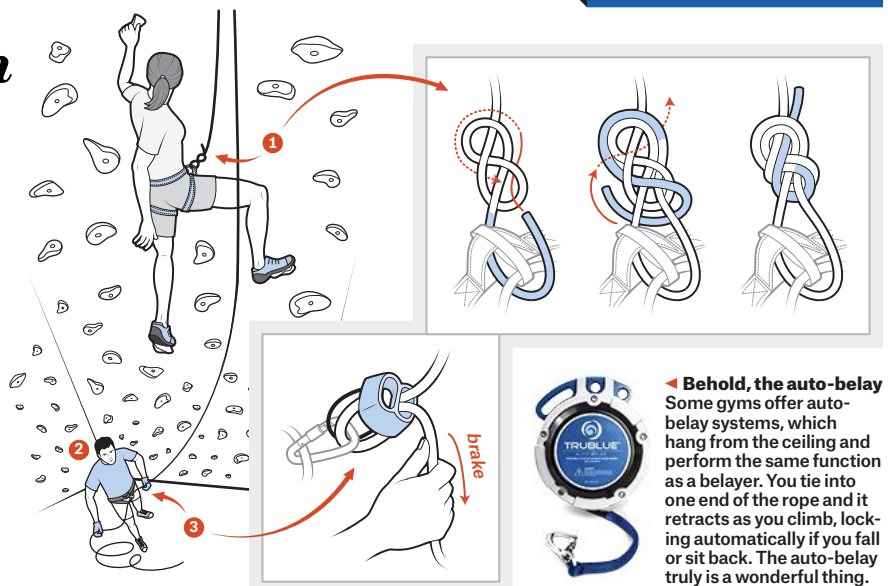
TIP! **CONSIDER LIQUID CHALK**
If you eventually move on to crack climbing—an advanced technique that requires jamming your hand into a crack for a hold—try Dry Hands All-Sport Grip (\$8), a liquid chalk substitute popular among football players. It'll keep your whole hand dry.



Strap In

Top ropers take note. If you plan to boulder, you can skip this part.

Tie your harness to a rope hanging from the ceiling using a figure-eight knot **1**. Your partner, the belayer **2**, will clip in to the other end using a carabiner attached to a belay device **3**, which looks a lot like the front of a pig's nose. The belay device functions as a friction brake, lightening the load the belayer has to support if you fall. As you move up the wall, the belayer removes slack from the line. If you lose your grip, or you're ready to come down, the belayer locks the rope in the belay device by pulling the free end out to the side, leaving you comfortably dangling. Most climbing gyms offer intro courses or lessons in both knots and belaying.



◀ **Behold, the auto-belay**
Some gyms offer auto-belay systems, which hang from the ceiling and perform the same function as a belayer. You tie into one end of the rope and it retracts as you climb, locking automatically if you fall or sit back. The auto-belay truly is a wonderful thing.



Pick Your Problem

UPON APPROACHING your gym's top-rope wall or bouldering course, you'll notice knobs and handles everywhere. How hard could it possibly be to climb a wall that's got more nooks than an English muffin, you might think. Here's what makes climbing hard: You don't get to use all the holds. You have to follow a preselected route, which climbers call a problem. Some gyms will mark a problem with colored tape. In other gyms you'll follow holds that are all the same color. The problem's difficulty is rated on one of two different scales, depending on whether you're bouldering or top roping. "Harder routes have worse holds—sometimes they're smaller, and sometimes they're harder to grab onto," Blair-Coyle says. "You might have fewer holds that are farther away, and you might be in awkward positions."

PROBLEM-RATING SYSTEMS

Sport Climbing

YOSEMITE DECIMAL SYSTEM

The Yosemite Decimal System classifies every kind of terrain a person can traverse from Class 1 to Class 5, be it a sidewalk (1) or a sheer cliff (5). Any wall worth climbing with hardware and a rope—in a gym or outdoors—falls into the top class, 5, and will be rated from 5.0 to 5.15 based on the route's hardest move, called its crux. The routes in most climbing gyms start at around 5.5. Beginning climbers will begin to sweat at about 5.7.

Bouldering

THE V-SCALE

Named for its progenitor, John "Vermin" Sherman, the V-scale—V0 to V16—grades bouldering routes. Because bouldering takes place on real or artificial boulders, which have more angles and are closer to the ground than top-rope routes, it can require more powerful moves. In general, a V0 is comparable to a 5.9 on the Yosemite System. "Each gym is different, but I'd say V2 and under is easy, V3 to V5 is medium, and then V6 and above is hard," Blair-Coyle says.



Bouldering courses rated a V6 or higher, such as the one Blair-Coyle is climbing above, have problems that require precarious positions and even leaps.



Climb

BEGIN AT THE HOLD marked start, put a hand on it, and crawl along the holds on your problem. Easier problems often have more holds than you need, so always choose those that will get you in position to best reach the next comfortable spot. There are tricks to moving your center of gravity around that you'll learn as you get better, but usually you want to reach for a new hold, move your feet up to a set of new holds, and then stand. Keep most of the weight on your legs, because your arms will tire first.

PRIMER: THE HOLD HIERARCHY

From easiest to hardest.



1. JUGS
Practically handles. Put your hand in the opening and grab.

2. PINCHES
A little like door-knobs. Best gripped between your fingers and thumb, like you're holding a can.



3. CRIMPS
These thin-edged nubs barely extend from the wall. Clench your fingers close to your palms to get your fingers on the top.



4. SLOPERS
Big, round bubbles with few irregularities to grip, slopers are best attempted with the help of friction. Feel for any defect that might help you, then get as much of your palm on the hold as possible. Hang directly away from the roundest part.

FIND YOUR INNER MONKEY

When faced with indecision, resist the impulse to contract your arms and hold close to the wall. Think like a monkey: A monkey doesn't cling to a tree but keeps its body relaxed while it hangs. "Climbing is really about learning to use your body so you're minimizing the strength you require," Blair-Coyle says. "You want to try to keep your arms as straight as possible when you can."

GETTING DOWN

If you fall, don't panic. Just alert your belayer by saying "falling." If you're not falling, but you've had enough, say "take." Either way, your belayer will lock the rope in the belay device, which he can do quickly. Then just sit back like you're sitting in a chair. Trust the rope. It will hold you. Kick gently off the wall as your belayer lets you down.

With thanks to Peter Steadman and Kate Mullen, owners of the Stronghold Climbing Gym in Los Angeles.

BREAKTHROUGH AWARDS 2015

After eleven years of celebrating the doctors and scientists, engineers and inventors, planets and popes most responsible for changing the world in our annual Breakthrough Awards, we asked ourselves: What constitutes a breakthrough? It's more than just doing something no one else has done before. (If that were the case we'd have to honor anyone who has considered voting for Trump.) It's doing something that no one else would think feasible. Like perfecting the robotic hand by building something that isn't a hand at all (see opposite). The people in the next twenty-one pages have propelled their industries—and our society—to new possibility. In ways that you may not immediately notice, they've improved your life. They've made Breakthroughs.



SEE MORE
BREAKTHROUGHS

THE NEXT ROBOTIC HAND

Different robot hands are designed, at great expense of time and money, to pick up different objects, their carefully calibrated robot fingers curling around the shape that needs picking up, be it a puppy or a jet-engine part. "There aren't many objects that can't already be gripped by a specific robotic gripper," says Bill Culley, president of **Empire Robotics**, a three-year-old company in Boston. Culley and cofounder John Amend wanted to create a robot that could handle a variety of objects with speed and precision—without needing to swap out hands. So they built one that doesn't use hands at all.

Their creation, the Versaball, picks up objects up to ten inches in diameter in as little as 0.7 seconds.

HOW IT WORKS

1. In a relaxed state, Versaball's squishy composite-rubber body is filled with synthetic sand. A valve releases air into the body, softening the sides and allowing the sand to flow.
2. The ball is lowered onto the object, conforming to its shape.
3. The valve pulls the air out of the ball, jamming the granular material together and hardening the ball's body. The ball keeps hold of the object for up to five minutes through friction from pinching, vacuum suction, or simple entrapment.
4. The valve pushes air back into the ball's body, loosening the sand and releasing the object.



A Much Faster Means of 3D Printing

Redefining on-demand production was nice, but 3D printing sure can be slow. At least it used to be.

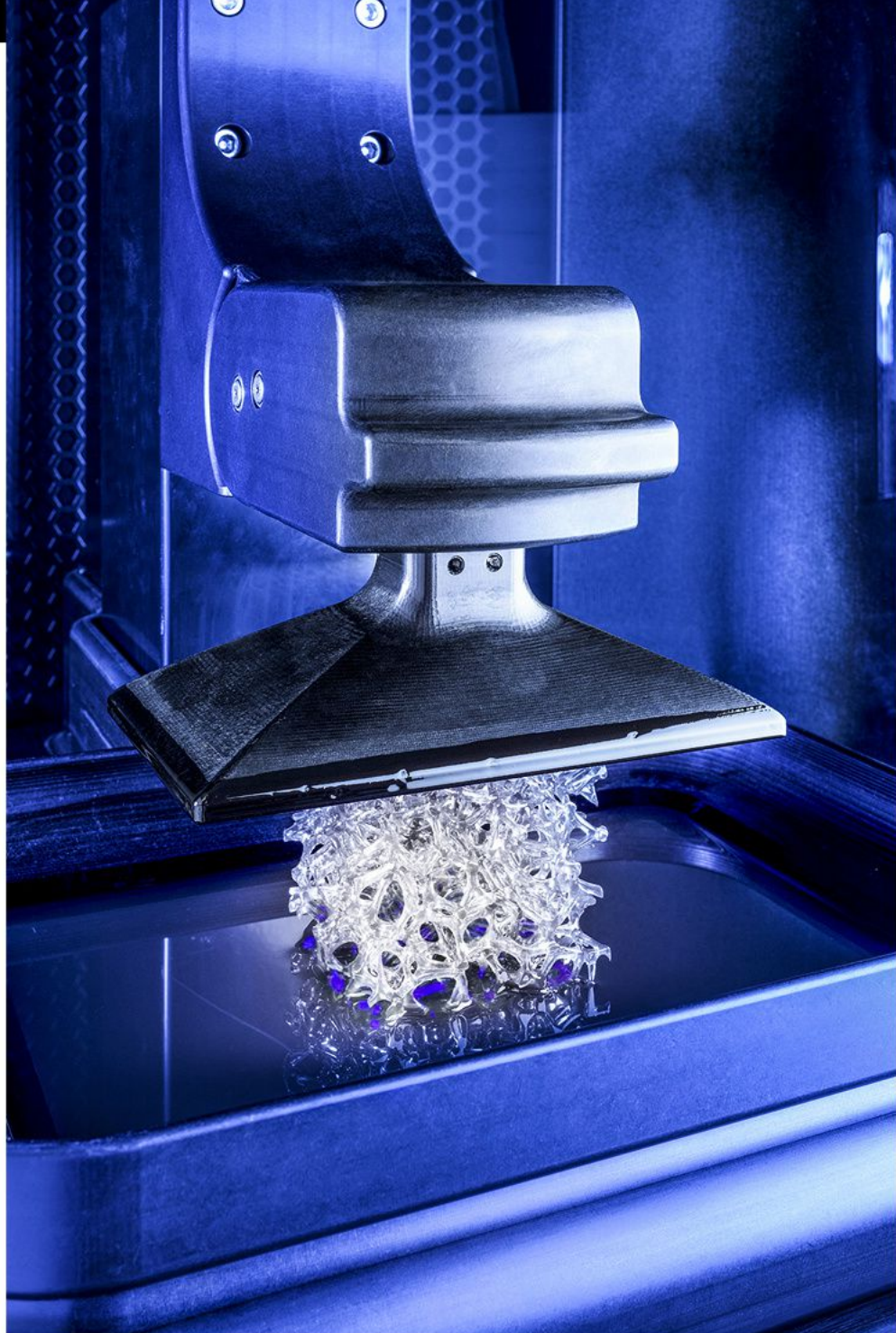
For all that it allows us to do, 3D printing has a major limitation: It's painfully slow. The current machines work by additive manufacturing. Like a hot-glue gun, the printer laboriously heats, drips, and dries plastic strands, depositing layer upon layer as it slowly builds each object. Printing a small plastic ball can take hours, and afterward close inspection reveals the rough and relatively fragile process that created it. That's what we would be stuck with if it weren't for the film work of Arnold Schwarzenegger. A group of chemists and physicists led by Joseph DeSimone at the University of North Carolina has completely reimagined 3D printing after being inspired by Arnie's *Terminator 2* nemesis, the liquid-metal-based T-1000.

Their company, **Carbon3D**, developed a technology called Continuous Liquid Interface Production (CLIP) that uses photosensitive resin that hardens when exposed to light and liquefies when exposed to oxygen. First the printer arm is dipped into a vat of resin. As the arm slowly lifts, the required shape is projected up through a window at the bottom of the vat. Oxygen is pumped in at specific times and at precise levels to inhibit and control the curing process. When the part clears the resin, all that remains is for it to be cut from the printer arm and rinsed of thermoplastic residue. Like tradi-

tional 3D printing, CLIP is mesmerizing to watch. It's also twenty-five to a hundred times faster.

Carbon3D claims the CLIP process works on a wide range of polymers with different characteristics, from spongy objects to extremely hard solids. It has created burn-resistant substances and is experimenting with embedding particulates, such as ceramics, to produce even more robust materials. The only bad news is that Carbon3D printers won't be available anytime soon for consumers. But the company does envision its printers in specialty stores, where you'll be able to print on demand—and not have to take a week off work while you wait.

—DAN DUBNO



Self-Steering Bullets

Announced this spring, **DARPA's** .50-caliber rounds are fitted with optical sensors that allow them to automatically change trajectory in midair. Not great news for bad guys.



Left: The Expedition 30 crew drinks tea from the first-generation zero-g cup in 2012. Below left: The first- and second-generation zero-g cups.

SPACE COFFEE



Contrary to images of astronauts casually floating around with big ol' smiles, we live and work in a dangerous, high-stress environment. When we complete a task, such as snagging the first commercial unmanned cargo spacecraft with a robotic arm or performing a delicate experiment with a virulent strain of *Salmonella*, afterward we might want to discuss it over a cup of coffee. But that experience isn't the same when you're sucking from a bag through a straw, the current solution. It works fine, but does not provide that connection between humans.

On Earth, when a straw is submerged in a cup, the liquid is drawn partway up into the straw. This is known as capillary rise and is driven by surface tension and the pressure difference caused by a curved meniscus. A straw's geometry can force the liquid to rise to the very top of the straw where it stops as if waiting for a pair of lips to come by for a sip. In the weightlessness of orbit, an open channel defined by two walls separated by a small angle essentially makes a straw. If the wall angle continuously decreases from the cup bottom to the rim, culminating in a tight angle mathematically known as a cusp, an imbalance in capillary forces moves the fluid from the bottom to the top. And as with a straw, once the fluid reaches the cusp, it stops and waits.

In this new zero-g cup (adapted from a much simpler first-generation design) there are no straight lines. This model has a spheroidal bulk region that morphs into an interior corner, which then tapers to a cusp at the lip of the cup. A capillary gradient drives the liquid toward the lip of the cup. In operation, you don't tip the cup toward your face. You merely make a connection by touching the cusp to your lips, as capillary forces automatically push the coffee into your mouth.

In four hundred years nobody will remember who invented this cup. But perhaps some future explorer will one day propose a toast on behalf of its inventors.

—DON PETTIT



Pettit is a NASA astronaut and the coinventor of the cup (with physicist Mark Weislogel of Portland State University in Oregon). The cup is specially designed to allow astronauts to have a more realistic drinking experience in space. Six cups were delivered to the International Space Station in April.



A DISASTER-RECOVERY DRONE THAT CAN TAKE A BEATING

There are a few things you can use drones to do:

1. Spy on your enemies.
2. Spy on your friends.
3. Deliver very light items over short distances.
4. Save someone's life.

It's that last one that led Adrien Briod and Patrick Thévoz, then graduate students at the École Polytechnique Fédérale de Lausanne in Switzerland, to create the Gimball. Inspired by the failings of search-and-rescue robots at Fukushima, which often encountered impassable, debris-clogged hallways, and traditional drones, which can be knocked down by the slightest impact, the Gimball is a drone surrounded by a carbon-fiber cage that protects the twin propellers from hazards. It's attached by a three-axis gimbal system,

so if the drone does run into something, the cage absorbs the impact. The drone itself remains stable. With an onboard hi-def camera capable of live streaming and recording and an ability to withstand collisions of up to ten miles per hour, the Gimball can go almost anywhere. Even if people can't.

Earlier this year their company, **Flyability**, won the UAE Drones for Good competition in Dubai and the million-dollar purse that comes with it. "The Gimball is the first drone that has a completely different field of application and does completely new things that people don't know about, and that opens a lot of opportunities when you see it," Thévoz says. Governments should be able to order the first Gimballs by the end of the year.





— When only a couple of people out of a hundred respond to a cancer drug, that drug is often shelved as a failure. But what if you're one of those two people?

By **KIRA PEIKOFF**

Illustration by **MATT HUYNH**

TUMOR



After a cancer patient loses the battle, when the funeral has ended and the mourners have returned home, the cancer remains. It doesn't go where the body goes, to the funeral home or the crematorium. The hospital doesn't throw it away. Usually a pathologist freezes a piece of a tumor, or bathes it in an embalming fluid called formalin and sends it out to be fixed in a paraffin block. Then he seals it in a clear biohazard bag, puts it on dry ice, and adds it to a stockpile of other samples, their identities stripped to random sequences of numbers and letters, all awaiting a journey to a biorepository, a tissue bank for samples such as these. There the cancer will wait among thousands of other samples, until a doctor somewhere thinks of a reason to want it.

These warehouses are catalogs of the difficulties inherent in treating the disease oncologist Siddhartha Mukherjee famously called the emperor of all maladies: Of the hundreds of drugs that move into development annually to treat cancer, only a few are safe and effective

enough to receive Food and Drug Administration approval. Despite advances in chemotherapy, proton therapy, and immunotherapy, techniques that employ drugs, radiation, and the immune system, respectively, to shrink tumors, more than 585,000 people succumb to the disease every year. Their tumors, fresh, frozen, or fixed in wax, build up in the tissue bank.

Oncologist-researchers, the united human front line against cancer, are accustomed to disappointment. They tend to be driven by the conviction that cancer can be beaten, in spite of the massive trove of evidence to the contrary. David Solit, an athletic forty-six-year-old with eyes as blue as a work shirt, is a perfect example. In medical school he chose oncology because his aunt had died of breast cancer. "I wanted to find better treatments for people who had incurable tumors," he says. He is not intimidated by the word incurable.

Back in 2010 Solit was in a meeting on the fourth floor of the Kimmel Center, a treatment space for prostate, bladder, and related cancers at Memorial Sloan Kettering Cancer Center in New York City, where he works. In a windowless conference space, some fifteen doctors, researchers, and nurses sat around a U-shaped table in white coats, discussing the hospital's clinical drug trials. The meeting was a weekly status update for a drug called everolimus, which blocks a protein called mTOR that makes cells grow and divide. Forty-five bladder cancer patients had received everolimus. Nearly all of them—forty-three—had no response at all.

The doctors considered scrapping the drug entirely. But then Solit asked a critical question: What happened to the other two? One patient had had a partial response. But the other had gone into complete remission. She had remained cancer-free for two years. "I knew from that one patient that enough of the drug got into her tumor for it to work," Solit says. "For me, that meant it was a good drug. We just didn't know who to give it to."

The patient was exceptional, and Solit intended to find out why.



cancer is not a single disease. In concept it is the growth of abnormal cells that spread around the body, overwhelming its systems like a weed in a garden. But what kind of weed it is and how fast it spreads are different in each case. Pancreatic cancer will kill you much faster, on average, than breast cancer. A type of lung cancer

that is caused by a mutation in the gene for a protein called KRAS is far more lethal than the same type of lung cancer caused by a mutation in the gene for EGFR. What makes cancer so difficult to beat is that the mechanisms are unique to each person and, indeed, to each cancer. A drug that causes remission in one case may do nothing in another.

Because a tumor's genetic background can direct poten-



National Cancer Institute oncologist Barbara Conley (left) and Memorial Sloan Kettering medical oncologist David Solit (right) are two researchers making progress toward a cure for cancer. Both have also lost family members to the disease.

tial treatments, researchers have been keen to genetically map tumors since the technology became possible in 2000. If oncologists could map a tumor's entire genome, goes the theory, they could compare it with a reference sequence made up of normal DNA. Mismatches might explain what caused the tumor to grow. Correcting the mismatch could cure the cancer.

And so Solit will be the first to tell you that discovering the genetic target of the drug everolimus was partly due to luck. In 2010 whole-genome sequencing, the technique that would eventually allow Solit to sequence the tumor from the woman who had the exceptional response, was on the cusp of availability. At first he and more than a dozen of his colleagues tried to study the tumor "the old-fashioned way"—one gene at a time. Tumor cells have approximately twenty thousand genes, the same as in a normal human cell, which made this an inefficient, and not particularly promising, undertaking.

Then came the luck: Illumina, a San Diego-based biotech company, engineered a digital DNA sequencing machine, a sleek tabletop lab-computer complex that could analyze the sequence of bases—A, G, C, and T—in millions of fragments of DNA, then reconstruct the fragments to show a tumor's entire raw genetic code. The cost of the experiment Solit dreamed of doing, sequencing the full genome, dropped from millions of dollars to

just \$20,000. (As computer power accelerates, the cost continues to drop: The same experiment today would cost only \$2,000.)

With the lower cost option available, the hospital contracted the sequencing out to Illumina, and, when the results returned, Solit and his colleagues began to sort through more than three billion base pairs' worth of data to figure out which one was relevant to the cancer. This is like trying to find a single misspelling in a book with six billion letters. It took six computational biologists five months to solve the puzzle. The exceptional patient had a mutation in two genes, called *TSC1* and *NF2*. Through a complex metabolic pathway, the mutations allowed mTOR, the protein affected by everolimus, to run wild, creating new, malignant cells all over. There it was—sense made out of a blind mess of human suffering. A protein that told cells to grow and divide like crazy. The drug that shut it off.

"It was incredibly exciting," says Solit.

After undergoing the peer-review process, Solit's finding appeared in the journal *Science* in 2012. It wasn't exactly the cure for cancer, but it did point in the cure's direction, and other leaders in oncology noticed. At the National Cancer Institute, a part of the National Institutes of Health in Rockville, Maryland, oncologist and developmental therapeutics researcher Barbara Conley thought

Solit's work could help her streamline testing for cancer drugs. In standard clinical trials for these types of drugs, patients are grouped according to the origin site of their cancer—prostate, breast, liver, brain. Then, depending on how the entire group responds during the test, a drug is either abandoned by the pharmaceutical company, or it's pursued through three phases of FDA trials until it is finally allowed on the market. Solit's work made Conley think patients could be grouped according to genetics instead.

"It would be nice if we could predict who will respond to which drugs," Conley says from her office on the fourth floor of the steel-and-granite National Institutes of Health building. She's in her early sixties, and has short hair and a warm smile. Her manner conveys a subdued enthusiasm—the cautious hope of a doctor acquainted with tragedy. Like Solit, she has suffered personal losses from cancer: Her father and all four grandparents died of it.

Soon after the *Science* article, Conley led the development of a new Exceptional Responders Initiative at the National Cancer Institute, which officially launched in September of last year. Today any oncologist anywhere in the country who has a patient who has responded positively to a cancer drug for at least six months can propose her case. The doctor sends an email without identifiers, but with enough details to assess whether the case is an exceptional responder, to a dedicated email address. Then a reviewing committee of doctors and scientists determines whether the patient is an exceptional responder, and the oncologist will call up one of those tissue banks and send in samples for genetic sequencing. Informativists at the institute will comb through the data looking

for mutations. Then the report will be given to researchers who assess whether the patient's drug response can be explained by his or her unique biochemistry.

Within two to five years the program's results may start to guide treatment decisions for the rest of us, eventually revolutionizing not only patient care but also the very nature of how drugs are tested. When you can determine what's causing a patient's cancer from the outset, the old standard of assigning patients to double-blind, randomized trials with a placebo arm and a treatment arm no longer makes sense. Trials will get smaller and more efficient, with drugs tested only in patients who have the right mutations and are most likely to benefit.

"You don't want to put extra people at risk," says Conley. "So we'll see smaller trials with higher response rates . . . that theoretically lead to faster approvals." To that end, the NCI is coordinating a new nationwide cancer drug trial that just started

this summer. At up to twenty-four hundred centers across the country, cancer patients who have eligible mutations will be matched with one of more than forty targeted drugs. As doctors have long suspected, the cure for cancer will actually be cures for cancer. And we're about to find a lot more of them.



ack at Sloan Kettering the personalized approach to cancer treatment is already under way. In May of 2014 philanthropists Marie-Josée and Henry Kravis donated \$100 million so the hospital could open a Center

for Molecular Oncology under Solit's direction. By July the center had rolled out the cutting-edge MSK-IMPACT test, a screening tool that looks for mutations in 341 genes known to be associated with cancer. Since the IMPACT test was introduced, more than five thousand

HOW TO DETECT CANCER: AN ALTERNATIVE GUIDE

The earlier a cancer is found, the better your chance of beating it. That's why researchers are constantly looking for new, better ways to detect the disease, many of which are unexpected. — SARAH Z. WEXLER



SCORPION VENOM

When removing brain tumors, surgeons want to remove as little healthy tissue as possible. To help discern the difference, Cedars-Sinai Medical Center in Los Angeles is testing "tumor paint" made from scorpion venom. It's injected into the patient's vein and makes the brain tumor glow under near-infrared light.



SOUND WAVES

Researchers at Carnegie Mellon University and Penn State University use sound waves to check cells, since healthy white blood cells and malignant cancer cells deflect the waves differently. Tests on human blood samples have been promising, and scientists are hoping for FDA approval.



BACTERIA

Bioengineers from MIT and the University of California, San Diego, engineered bacteria to produce an enzyme, LacZ, when it encountered tumors. They fed the bacteria to mice, then injected them with a molecule that makes the mice's urine glow if it binds with LacZ. Trials detected liver tumors as small as one cubic millimeter.



BREATH

The Nanoscale Artificial Nose, codeveloped by researchers at the University of Colorado Cancer Center, analyzes volatile organic compounds in the breath. After patients exhaled into the device, the NaNose was 85 percent accurate in distinguishing patients with early lung cancer from those with benign lung problems.



DOGS

In a 2014 study at the Italian Ministry of Defense Military Veterinary Center, two German shepherds trained in explosives detection were taught to find volatile organic compounds tied to prostate cancer. The dogs sniffed the urine of men with and without prostate cancer and were able to detect it correctly more than 98 percent of the time.



GOOGLE X

Google's experimental division is working on an ingestible pill made of specialized magnetic nanoparticles that can bind to cancerous cells. The infused cells could then be tracked and counted by a wearable device, helping doctors see where and how quickly the cancer is spreading.

patients have been screened, at a rate of five hundred per month, which will increase to a thousand a month by the end of this year. If the test finds a known, treatable mutation, the patient is eligible for basket studies, new clinical trials in which patients are enrolled and treated based on their tumor's genetic profile rather than on where it is.

In Solit's windowed corner office overlooking East Sixty-Ninth Street, the doctor spins in his desk chair to face his computer, where he brings up two PET scans for a late-stage metastatic breast cancer patient who was treated in a basket trial after receiving the IMPACT test. "We've seen some dramatic responses," he says. He gestures to the first image, a pretreatment scan of the patient's body that looks like a target from a shooting range, lit up with between fifty and a hundred red dots, all of them tumors. The second scan shows the same patient after eight weeks in a trial for a drug that inhibits some of the functions of a protein that was malfunctioning to cause her cancer. The second scan is completely clear.

Rita Porterfield, sixty-five, is another patient whose life has been extended thanks to the IMPACT test. After fifteen years of suffering from intractable bone pain, Porterfield was diagnosed with a rare disease called Erdheim-Chester, for which there are no FDA-approved treatments. By 2013 she was so ill that she couldn't walk. Her doctor gave her only a few months to live.

But genomic profiling showed that she had a mutation in a gene called *BRAF*, which leads to the production of an abnormal protein. A drug that inhibits this abnormal protein, called vemurafenib, already existed for melanoma patients, though it was not approved for Erdheim-Chester. By enrolling in a basket trial, Porterfield received free access to the drug, which otherwise costs \$14,500 per month.

"I was on the pills for three days when I told my husband, something's happened, something feels different," she says. "All of a sudden I started to get stronger and a little better at balance." Six months later and eighty pounds lighter, she was running around with her grandchildren, and playing bells and piano in her church choir. "I have a life again," she says. "It's a fun life now."

Even as experiences like Porterfield's hint at the end of cancer as we

know it, they reveal another, more insidious barrier to care: Genomic profiling may revolutionize the way we treat cancer, but our lumbering medical infrastructure might take a while to catch up. A drug may be FDA-approved, but insurance can still refuse to pay for it unless it's a "standard of care" in a given cancer. Genomic screening tests may not be covered for the same reason.

"Maybe the money's not coming from the traditional insurance system," Solit says. "We then have to rely on the generosity of people who believe this is making a difference." Sloan Kettering plans to pay to screen the majority of advanced cancer patients who walk through its doors—some ten thousand of them annually—out of its own funds.

Every year Solit participates in one of the annual indoor cycling events for the cancer charity Cycle for Survival, which has raised \$76.5 million for research and treatment so far. The cause is personal for him and not just because of his patients or his aunt. In March of 2014 Solit's sister-in-law died of breast cancer at age forty-three. For a cancer doctor, this is a particularly egregious insult: The very disease you've dedicated a lifetime to studying lashing out at your own family. But this is how cancer works—a tiny defect that is with you from the beginning, like a ridge in a fingernail, that spreads to crash the entire system. You can't protect anyone from it.

In his office, Solit looks at a picture of himself and his wife pedaling at last year's Cycle for Survival fundraiser. "Nobody wants to die at any age," he says. "But I do think that we can do better." After all, the ultimate goal of cancer research isn't immortality—we're all going to die. What Solit wants is what all doctors want: to give his patients the fullest life they can have, for as long as they have left.

But figuring out how to do this takes time, and a weed has no concern for human timetables. A weed cares only about expanding its territory. While Solit searches his patients for the underlying defects that caused the weed to grow in the first place, the weed germinates somewhere else. It proliferates. It overwhelms. During cancer's millennia-long history, it has always gone this way. Except when it hasn't. And those few, wonderful times just may save us yet.



A FLAT-PLANE ENGINE IN AN AFFORDABLE CAR

Flat-plane crankshafts are the stuff of exotics and race cars. Traditional V-8s are smoother and naturally well balanced, but flat-planes alternate ignition between the cylinder banks, allowing better breathing at high rpm. So while traditional 90-degree V-8s issue a throaty lope at idle and a deep bellow at higher rpm, flat-plane (180-degree) cranks hum impatiently at low rpm and bark out a staccato banshee scream at redline. If you've heard a Ferrari V-8, that's the flat-plane howl, the sound of refinement sacrificed for outright horsepower. And now it's the sound of the Mustang, as the new generation of Shelby GT350s gets the first flat-plane engine in Ford history. It's a barbarian—a 5.2-liter V-8 that redlines at 8,250 rpm and makes 526 horsepower without resorting to turbos or a supercharger. It won't be as silky as the GT's 5.0-liter V-8, but that's the point.



Live Translation Over the Phone

Microsoft's new Skype Translator translates video calls into six different languages in real time. As users speak, a Skype Translator bot recognizes and corrects the speech before translating verbally and onscreen. All for free on Windows 8 and 10 devices.

The Monitors of the Sea

How two guys in Montana are changing the way we study oceans.

You know Montana. Big state. Beautiful. Also: completely landlocked. More than four hundred miles from salt water, and that's if you're heading in the right direction. Despite that, a company in Missoula called **Sunburst Sensors**, founded by chemist Mike DeGrandpre and mechanical engineer James Beck, is somehow at the forefront of oceanic research. It took some ingenuity—the two constantly found themselves asking friends to bring back water samples whenever vacations took them to either coast—but two years ago Sunburst entered two X Prize Foundation challenges (which were originally announced at the Popular Mechanics Breakthrough Awards ceremony in 2013). One was to create a highly accurate pH sensor that could withstand a depth of three thousand meters. The other was to make a shallow-water sensor that costs less than \$1,000 and measures pH more accurately than what's already available. Sunburst won both. And \$1.5 million.

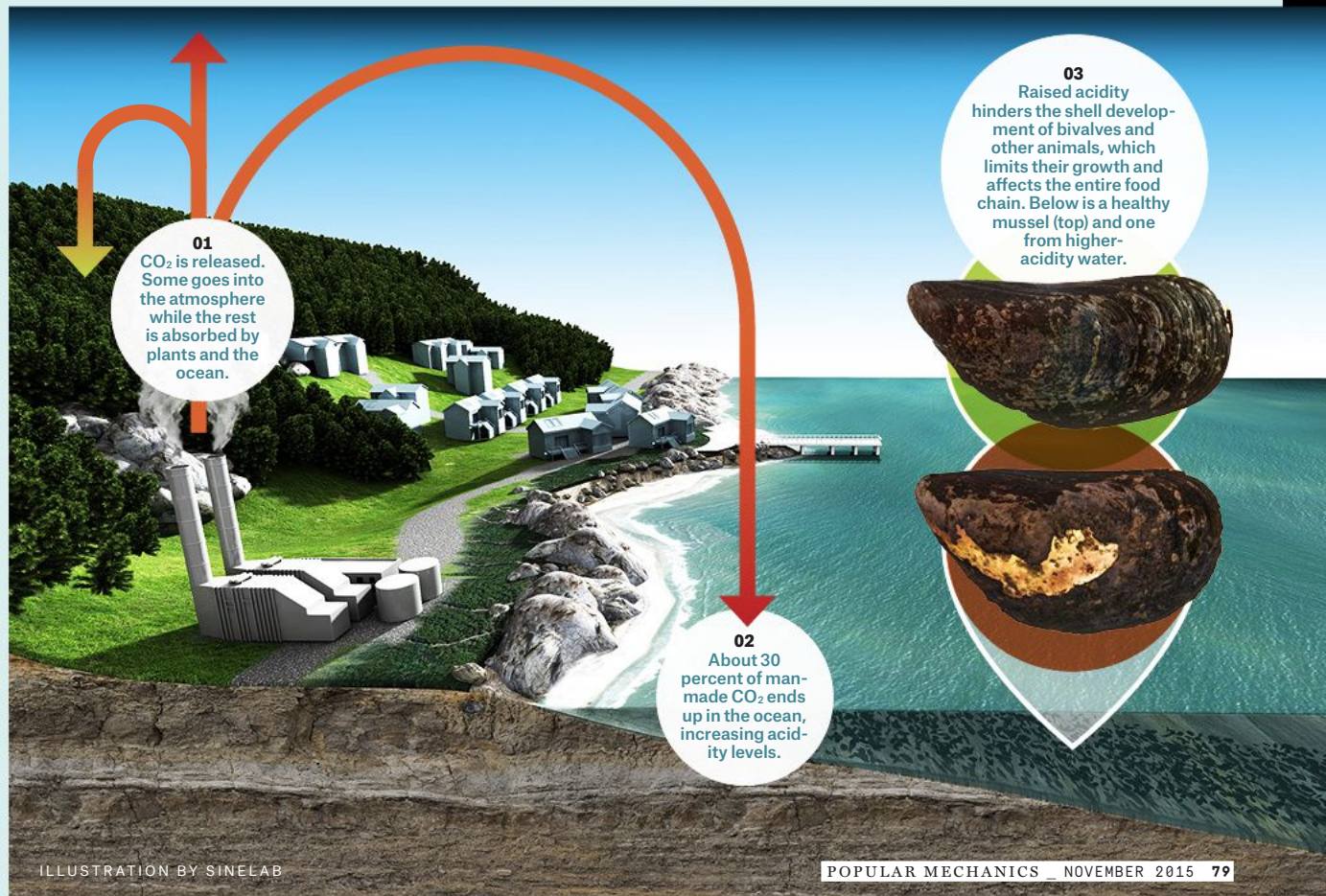
In the last 115 years ocean surface temperatures rose almost 1.5 degrees Fahrenheit, while pH levels decreased by 0.1 percent. Those seemingly small numbers have big implications. Of all the carbon humans spew into the atmosphere, about a third is absorbed by the oceans, resulting in this acidification. Today our oceans are roughly 30 percent more acidic than before the Industrial Revolution. This could be devastating to coral reefs, bivalves, and other marine life—pretty much everything that lives in the sea.

To create their winning entries, Sunburst (which has been making commercial freshwater and marine sensors since 1999) modified its preexisting Submersible Autonomous Moored Instrument (SAMI) pH sensor. A new

Coral is sensitive to changes in ocean temperature and chemistry, such as heightened carbon levels. A healthy coral reef (top) and a damaged, or bleached, reef.



titanium housing containing all of its parts made the SAMI tough enough for the deep-water challenge. Replacing pricey components and revamping sensor functions resulted in a SAMI more accurate, efficient, and less expensive than comparable sensors. With these new tools, more scientists will be able to study pH levels, and at greater depths, than ever before.



The Shutterbug Space Probe

Nine years and three billion miles after launching, NASA's New Horizons has changed the way we see our universe.

BY CHRIS HADFIELD



Hadfield, a retired astronaut, was the first Canadian to walk in space. His 2013 rendition of David Bowie's "Space Oddity," filmed aboard the International Space Station, has received more than twenty-six million YouTube views. He is also the author of the book *An Astronaut's Guide to Life on Earth*.

When the New Horizons probe launched from Cape Canaveral back in 2006, its three-stage rocket pushed it to more than 36,000 mph, making it the speediest ship ever built. It went past the moon in just nine hours. Even after coasting in the sun's gravity for nine years, it was still clocking over 32,000 mph this July when it finally swept past Pluto, three billion miles away. That's nine miles *per second*.

In 2013, as I orbited Earth for five months on the International Space Station—at a mere five miles per second—I often thought of New Horizons racing across our solar system like some hypersonic go-kart. And every time I took a picture of our world, I imagined the problems the probe would eventually have photographing Pluto.

The ISS has several windows facing straight down, like a glass-bottomed boat. I would hook my toes around a handrail to stabilize my weightless body, hold the digital camera and lens gently in my hands, carefully pivot while focusing, and smoothly push the shutter. Then I'd check the display to see how it looked.

Even with my extra care, the pictures would often be blurred or dark. I hadn't tracked the ground quite right, or my heartbeat had moved my floating arm and hand at just the wrong moment. Either way, I could try again the next time I came around Earth, ninety-two minutes later.

It made me dread what it was going to be like for New Horizons out by Pluto, and for her engineers sweating it out back on Earth. There would be only one try, with no do-over. Every command took more than four hours to get there, so it all had to be predicted and programmed. And the sensors were bolted directly to the probe, so the whole contraption had to turn as Pluto passed, like a photographer in a body cast.

Yet, somehow, they got it spectacularly right. As each clear new image arrived, I was astounded—like a kid watching fireworks. The mile-high mountains of solid ice. The huge, flowing nitrogen-

methane glaciers. The asteroid scars. The whisper-thin atmosphere being slowly blown out to space by the solar wind. Even as a veteran of three spaceflights, it amazed me.

And still New Horizons races on into the eternal night, on the hunt for even farther planetoids. Our distant emissary, patiently staring, making discoveries at a speed we can barely imagine.

Pluto, August 14, 2015.





PROSTHESES CONTROLLED BY YOUR MIND

Easton LaChappelle revolted against the staggering cost of prostheses by designing an inexpensive model in his bedroom. Then he did something even more impressive: He gave away the plans for free.

Like all good breakthroughs (or at least the one on page 72), this one goes back to the cinematic oeuvre of Arnold Schwarzenegger: "My parents definitely let me watch *Terminator* too young," says nineteen-year-old Easton LaChappelle.

At age fourteen, having experimented with electronics since grade school, the Colorado native became fixated on building a robotic arm. But his aim was far more altruistic than creating a cybernetic army. After an encounter at a local science fair with a seven-year-old whose prosthetic arm had cost \$80,000, he vowed to invent a prosthesis that was as technologically advanced as it was reasonably priced. Using fishing wire, Legos, electrical tubing, and toy-plane motors, LaChappelle assembled a prototype in his bedroom for less than \$400. Subsequent models were made with a 3D printer and incorporated an EEG headset to read brain waves. They earned him a trip to the White House to meet President Obama, a NASA internship, a TED Talk, and, ultimately, startup capital from multimillionaire motivational speaker Tony Robbins.

With that financing, LaChappelle cofounded **Unlimited Tomorrow** in 2014. In addition to further evolving the RoboArm, as it's now called, the Durango-based company is developing an exoskeleton for paraplegics as well as a revolutionary nonjoystick control system for existing robotic platforms.

Since LaChappelle began his work, the need for affordable prostheses has grown only more urgent. According to a 2010 study by the U.S. Department of Veteran Affairs, a prosthesis for a soldier who has lost an upper limb in the Iraq and Afghanistan conflicts will cost a lifetime minimum of \$560,000. So rather than wait a few years for Food and Drug Administration approval and its attendant fortune, LaChappelle announced at January's Consumer Electronics Show that Unlimited Tomorrow would make the first version of the RoboArm design open-source via its website. Completely free.

"It just got to the point where we wanted to get it to the people who really need to use it," he says. "We're focused on improving human life."

The money can always come later.

Concrete That Can Withstand a Bomb Blast

▶ In the predawn darkness in April 2013, the attackers snipped telephone cables near Pacific Gas and Electric's Metcalf transmission substation outside San Jose, California. They systematically shot and knocked out seventeen of the transformers that power Silicon Valley. Within thirty minutes they were gone, leaving \$15 million of damage behind them.

Although few Americans know about this attack, it exposed the vulnerability of our electrical grid. In response, the Federal Energy Regulatory Commission demanded that utilities protect their substations. But it didn't say how. This year Oregon-based **High Impact Technology** (HIT) announced a solution: four-inch concrete walls that can withstand bomb blasts, bullets, 120-mph winds, and fires burning at 2,200 degrees Fahrenheit. That's more than a slight improvement on the existing technology. "When most of the grid was built, in the thirties, forties, fifties, and sixties, international terrorism or domestic terrorism wasn't part of the conversation," says HIT director of operations Russ Monk.

The new walls are reinforced with composite rebar that's twice as strong as steel, which forms a skeleton underneath a layer of high-grade reinforced concrete. An external rubberlike coating binds to the face of the concrete, allowing the walls to absorb cracks from the impact of blasts and bullets. Whereas normally it takes eight inches of solid concrete to stop a bullet, HIT's walls do it with four. And one of those is extra, added to handle wind load.

AN EVEN FASTER TESLA

▶ Tesla's P85D was already a 691-hp particle beam of a sedan, with an Insane Mode that unlocked 3.1-second 0-to-60-mph sprints. So Tesla, naturally, gave it more power. The new Ludicrous speed provides 762 horsepower, 0 to 60 in 2.8 seconds, and

a 10.9-second quarter-mile. Thus making the Model S P85D the only ten-second sedan, and Tesla the only company with the sense of humor to reference a Mel Brooks space comedy.





Dave Masten in his bare-bones hangar at the Mojave Air and Space Port.



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— • Deep in the California desert,
an unknown entrepreneur is competing against
famous billionaires for a chance to build
the government's next great spacecraft.
He's outmanned
and out-financed.
And he just might pull it off.

By JOE PAPPALARDO

Photographs by KEVIN COOLEY



Dave Masten stares at his computer screen, finger poised over the mouse button. He knows that opening this email, sent by the Defense Advanced Research Projects Agency, the Pentagon's advanced technology lab, will change his life. One way or the other.

This email is the fulcrum of his future. It is either an acceptance letter or a rejection letter for his company's proposal to build what DARPA calls XS-1: an experimental unmanned space plane that can fly ten times in ten days, reaching a speed of Mach 10-plus and lifting payloads greater than three thousand pounds to orbit, at a cost of no more than \$5 million per flight. Being accepted as one of the three competing contractors represents the best shot that Dave Masten—perennial underdog, Silicon Valley refugee, scrappy space-industry entrepreneur—will have to build a working spacecraft. It would mean an immediate infusion of \$3 million, with more coming the next year. The final contract could be worth as much as \$140 million.

Being rejected would mean the status quo: toiling in the desert in continued obscurity, with a thin profit margin and languishing dreams of building orbital spacecraft. It would also be the loss of a rare opportunity. Historically, government launch programs favored—if not outright mandated—spacecraft that could return to Earth on a runway or under parachutes. But Masten's rockets use a vertical-takeoff, vertical-landing design—no runway or parachute required. The XS-1 program allowed for this design. There was no telling if the

government would continue the allowance for future launch programs. This could be his only chance.

One email, two roads. One leading straight to space.

Double-click.

Masten reads slowly and deliberately. Then he turns to the engineers gathered near his desk, nonchalant, and says: "I've got some good news and bad news. The good news is we've been selected for XS-1. The bad news is we've been selected for XS-1."



The Upper Mojave Desert is like some terrifying postapocalyptic dream: abandoned gas stations covered with hieroglyphic graffiti, battered highways streaked with moldering roadkill. Mountains. Heat. And that endless, empty blue sky.

Except it's not entirely empty. The western United States is home to the R-2508 Complex, the epicenter of American military aircraft training. F-16 Fighting Falcons, F/A-18 Hornets, and F-35 Lightning IIs from local air bases and training centers tear through twenty thousand square miles of protected airspace, just as Chuck Yeager did when he broke the sound barrier here sixty-eight years ago.

Though closed to passenger planes and private flyers, the airspace is open to tenants of the nearby

Mojave Air and Space Port, which was certified as the country's first commercial spaceport in 2004. Masten moved in that same year, after Cisco Systems bought the startup where he was working as a software engineer. He had his choice of several empty buildings. He picked a beat-to-hell former Marine Corps barracks from the 1940s with a leaky roof and crawling with black widow spiders. It was perfect. The twenty-foot ceilings were plenty high enough for the launch vehicles he was designing—just him and the three guys working for him. Even better, he secured several launchpads from which to fly his fleet.

For the next few years the only people who knew Masten Space Systems existed were a handful of industry insiders and fellow spaceport tenants—which included some of the biggest names in the private space business, like industry forefather Scaled Composites and Richard Branson's Virgin Galactic and Paul Allen's Vulcan Stratolaunch Systems, their massive hangars housing pieces of manufacturing equipment that cost more than the entire net worth of MSS. But then in 2009 the company won a \$1 million NASA-sponsored lunar lander competition, and suddenly it had a little recognition and a lot of business. Its rockets were regularly hired out by NASA, the Department of

Defense, and top universities for high-altitude experiments and research.

MSS gained even more respect after being selected as one of the three XS-1 competitors. The other two: mega defense supplier Northrop Grumman and Boeing. And not only them. Boeing was working in partnership with Blue Origin, the aerospace company belonging to Jeff Bezos, while Northrop Grumman was working with Scaled Composites and Virgin Galactic. MSS, meanwhile, had teamed with another tiny Mojave firm, XCOR Aerospace. So to build his company's first spacecraft, all Dave Masten had to do was beat out the most advanced, well-financed aerospace firms in the world. And he had just thirteen months before the next round of judging.



This past August, just a couple weeks before the announcement of those results, Masten recounts the day of that fateful email over breakfast at the Voyager Restaurant, on the ground floor of the spaceport's administrative building. It's a greasy spoon on the spaceport grounds that doubles as a shrine to the seventy-two-year-old founder of Scaled Composites, Burt Rutan, and is named after his plane, *Voyager*, which in 1986 became the first aircraft to circumnavigate the globe without stopping or refueling. A map of this quest covers one wall.

The commercial space industry is dominated by outsize ambition: Rutan, Branson, Allen, Bezos, Elon Musk. Each considers himself to be a true avatar of the future of spaceflight. Masten is different. He's from Cleveland, for one thing. He doesn't evangelize. He doesn't want to be bothered with micromanagement and self-aggrandizement. His title at the company he founded is chief technology officer, not chief executive officer. He's plain-spoken. Not antagonistic or antisocial. He'd just rather be working than giving interviews is all. He eats his omelet quickly and then it's right back to the garage.

It is only slightly less ramshackle than when Masten

took it over. The roof still leaks, and you still have to watch out for black widows. Tool chests line the walls, which are bare except for company banners, a whiteboard filled with equations, and an American flag. In the middle of the hangar is a Masten rocket called the Xaero-B, standing on four spindly metal legs with two large spherical tanks stacked atop each other. One tank is meant for isopropyl alcohol fuel, the other for cryogenically chilled liquid oxygen. Another ring of tanks circles its waist: canisters of helium, used for the reaction control system thrusters that help orient the vehicle. The engine at the bottom is gimbaled to give the threadbare insectoid craft the ability to steer.

Several employees attend the craft, prepping it for an upcoming experiment by the University of Colorado, Boulder,

rocket vehicles meant for carrying supplies, not astronauts or tourists—the spacecraft equivalent of semitrucks that might one day cart oxygen and hydrogen from the lunar surface to some Lagrange point filling station between Earth and the moon. This is why his rockets use a vertical-takeoff, vertical-landing design. “It’s the one landing method I’m aware of that applies to every solid body in the solar system,” he says. “You can’t land an airplane on the moon.”

Vertical takeoff and

A rendering of Masten Space Systems’ vertical-takeoff, vertical-landing XS-1 space plane.



to prove that spacecraft can communicate with ground-based telescopes and thus help find exoplanets.

Masten’s small company and its location attract a certain kind of dedicated, badass engineer-mechanic. “I interned at Boeing in the 777 propulsion department,” says Kyle Nyberg, twenty-six. “Good people, good company. But I got very restless sitting in an office all day. I assumed the next forty years of my life would be spent like that, and it really freaked me out. In a small, scrappy company like Masten, the engineers are given both the pleasure and frustration of fabricating their designs with their own hands. It’s very uncommon.”

He and his coworkers wear T-shirts that say MOON FIRST, a core company belief about the best destination for NASA’s next mission and another way in which Dave Masten differs from the industry’s famous billionaires. While most of them dream the big dream of open access to space and the fantastical future that comes with it—intergalactic vacations and Mars colonies and all that—he advocates more utilitarian aims.

“They started off trying to build a 747,” he says of his contemporaries, “but we haven’t even figured out how to fly yet.”

Masten’s primary focus has always been devising

vertical landing are also key to reusability. Some of Masten’s rockets have flown hundreds of times, and they can be readied for relaunch in less than a day. The XS-1 competition goal of ten flights in ten days? That’s approaching routine for Masten. The other two teams haven’t done it once.



A couple weeks later DARPA would announce that all three teams were advancing to Phase 1B of the XS-1 competition, for which they’d each receive an additional \$6 million. Phase 1 focused on design and infrastructure plans—i.e., prove you can do it. Phase 1B is devoted to flight tests, compiling related data, and further design work on the aeroshell—prove *how* you’ll do it. The results of Phase 1B are expected next summer, with the first XS-1 orbital mission to take place as early as 2018.

Whatever the outcome, Masten’s simply making it this far has vast implications for the private space industry. “It changes the game,” says Hannah Kerner, a former NASA engineer and the executive director of the Space Frontier Foundation. “DARPA has not only opened up the playing field for commercial space companies but has recognized these newer, agile companies as serious players.”

The irony is that should Dave Masten pull off the upset he would likely no longer be able to stay so agile. He would have to scale up to meet the payload and performance requirements. He would have to hire more staff. He would have to abandon the slow-and-steady strategy. He would no longer be the underdog.

“The XS-1 is maybe a bigger step than I wanted to take,” he says, “but it’s a step on the path. We are going to orbit.”

Even without the XS-1 contract, MSS can’t really claim also-ran status any longer. In August it opened an office at Cape Canaveral, the Florida space center that is reinventing itself as a crucial hub for commercial launch companies. There MSS resides in the same strip-mall business park as SpaceX, not far from one of the key gates into Kennedy Space Center.

Still, Masten Space Systems is undermanned and underfunded, a ragtag bunch out in the desert, drilling and hammering and soldering in their small badlands garage down the block from the rich folk. They’re still the ones to root for.

“I think we can be competitive,” is all Masten would say about his chances in XS-1. It would do him no good to overpromise anything—something other space-industry upstarts have a habit of doing. Some great men speak greatly, and it is that ability that helps them be great. Masten is the other kind of great. Quiet. Hardworking. Understated. But, in his own quiet way, as insatiable in his desire for progress as the rest of them.

In the garage a sonic boom, courtesy of a military jet high above the desert, cracks like an overhead cannon shot. Dust sifts into the air and the warehouse’s metal doors rattle. Masten doesn’t even flinch.

PM



The New Way to Watch Baseball

On June 23 Miami's Giancarlo Stanton hit a massive 478-foot two-run homer, his twenty-sixth of the season. But it wasn't the distance (he's hit longer) or the tally (it certainly wasn't his last) that had fans talking and the front office giddy. It was the searing 119.2 mph at which the ball came off his bat, one of the fastest home-run balls of the year.

With the introduction of Statcast, exit velocity is now part of the baseball vernacular, as is the ability to assign cold, hard metrics to

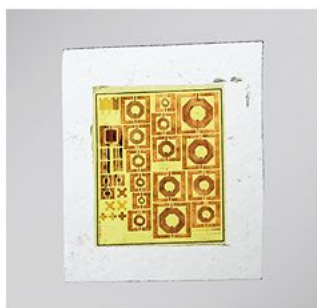
our amazement. This year **MLB Advanced Media** (the nimble digital arm of Major League Baseball) installed the two-pronged tracking system—a radar sensor above home plate and a set of stereoscopic cameras along the third-base line, which together collect data on the ball and the players during every play—into each of the thirty major league ballparks. All of those cameras create an impressive average of seven terabytes per game. In order to turn that information into something that both

teams and fans can understand and use, whether for recruiting or winning barroom arguments, MLB enlisted New York University mathematicians to develop advanced algorithms that crunch the numbers in real time. Now, seconds after a play, broadcast graphics can cite the rate of spin on a thrown ball (like the 2,560 rpm off the fingers of Cincinnati closer Aroldis Chapman), critique the efficiency of a base runner's path, or marvel at the launch speed of that Stanton homer.



The Pope for Our Time

Pope Francis is on Twitter. That would be enough. But this year, he issued a letter to the world acknowledging that global climate change is real, and that it's partially caused by humans. Then he convened a meeting of world mayors and governors to address the problem. God bless.



COMPUTER CHIPS MADE OF WOOD

Your TV, phone, and Xbox are hard to get rid of, and not just for sentimental reasons. The electronic devices we use every day are powered by microchips, and those microchips contain precious or harmful elements like silicon, gold, gallium, and arsenic. You don't want these things sitting in landfills, where the chemicals can leak into the ground. But right now that's exactly what many do. This issue prompted an idea from **University of Wisconsin-Madison professor Jack Ma and his team**: Why not make the chips out of wood? The crucial circuits are still made of silicon or gallium arsenide, but in a quantity up to five thousand times smaller than that of typical chips. Those circuits, about a hundred nanometers thick, are placed on a base of cellulose nanofibril—wood that has been broken down to the nanoscale, then reassembled into what is essentially a thin, durable paper. The result is a biodegradable, environmentally friendly microchip. Consumers won't be able to buy the chips directly, but Ma says that three major computer chip manufacturers could soon be making them.

—JAKE CAPPUCCINO

Deanne Bell Makes Kids Want to Be Engineers

It helps that they might get to interview an astronaut.

BY ROBERT VRABEL

Say you've come up with a great idea. Could be a plan for a new business or a way to bolster the dwindling Asian elephant population. Who do you tell? Your mom? Your best friend? Deanne Bell told NASA.

The accomplished mechanical engineer and television host (PBS's *Design Squad*, Discovery Channel's *Smash Lab*) got involved in STEM education in 2008. "I started speaking to kids about engineering careers and the diversity of things you could do as an engineer, and it kind of grew from there," she says. When Made in Space, a California-based engineering firm, announced the Zero-G Printer, a 3D printer designed to work aboard the International Space Station (the first of its kind), Bell had her epiphany. With the support of NASA and Made in Space, she started Future Engineers, an educational platform with an emphasis on inspiring a new generation of innovators. Each year the organization holds a competition for kids to design objects that could be 3D printed and used on board the space station. Their creations are submitted to the website, futureengineers.org, which also provides instruction videos that teach kids basic scientific principles and elements of 3D design. The inaugural challenge started on September 21, 2014, the very same day the printer was launched into orbit.

The competition asks two groups of kids (broken into junior and teen categories) to create and submit 3D models of containers that would

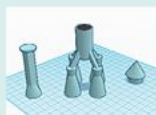
prove useful in the zero-gravity environment of the ISS. Among the hundreds of submissions were an arched food cover that keeps your dinner from flying away, a space football, and an innovative adjustable finger splint. Bell believes that no entry is too intricate (a fruit fly habitat with its own oxygen generator). Or too simple (a bobby pin). "We encourage all students to dive in," she says. Four finalists are selected to answer questions from astronauts and ISS personnel regarding their designs. One of last year's winners will be brought to a NASA facility to watch his design (a multitool) be printed live in space. For a look at this year's entries, including a cage that keeps nail clippings from puncturing any of the important tubes in the space station, head to futureengineers.org.



A FEW OF THIS YEAR'S ENTRIES



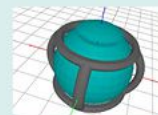
Collapsible Container (teen division): Expand or compress to fit different contents. The screw-on lid has a built-in handle.



Cookie Dispenser (junior): Stack the cookies over the plunger in the center tube, put the cap on for freshness, dispense when hungry.



Zero-G Fluid Cleaner (teen): A device to process urine into drinking water. (Wisely leaves the actual filtration process up to NASA.)



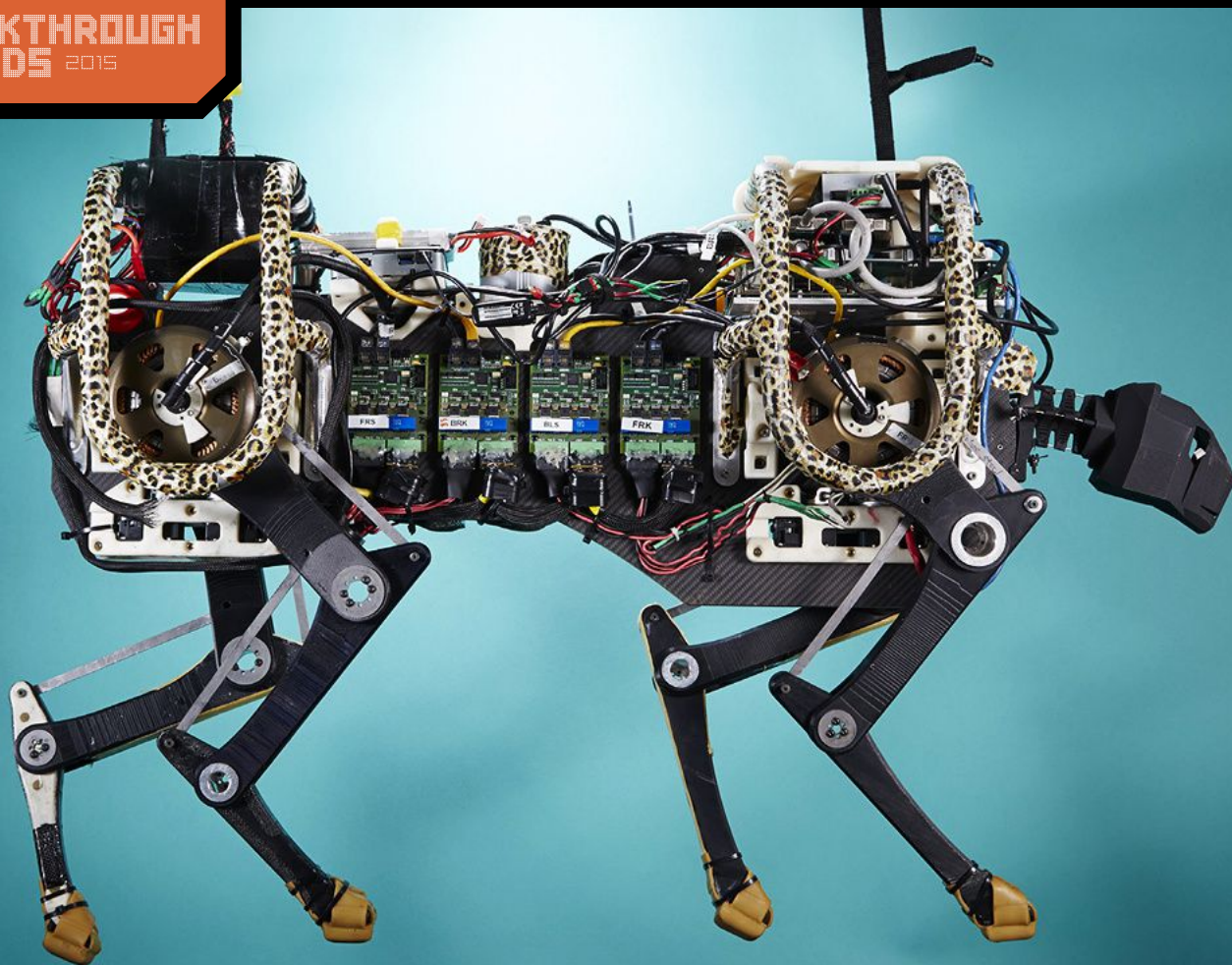
Rodent Space Runner (teen): A hamster ball with a frame that uses Velcro to attach to the wall and keep the ball in one place.



All-in-One Container (junior): Reservoir with drinking spout and three storage bays that can be closed with plexiglass or Velcro.



Sweet Smell Fly Trap (junior): Uses a piece of fruit and a one-way entrance to trap any flies that may escape from experiments.



THE ROBOT CHEETAH CAN NOW JUMP

When MIT's robotic cheetah was introduced in 2013, it was a big deal. Yes, it looks more like a buffalo and can scamper only about thirteen miles per hour, but "its applications are world changing," says project leader Sangbae Kim. This year the cheetah became an even bigger deal. Along with the ability to run without support, it can now use its LIDAR system to "see," adjust to, and jump over obstacles at five miles per hour—on its own, with no human input. While the cheetah could be used in military applications such as recon missions or traversing dangerous ground, Kim envisions a world where wheels are essentially obsolete: new accessibility for people who once used wheelchairs, faster and more robust disaster relief, and travel that is no longer hindered by the need for flat, paved roads.

A BETTER BOMB TEST

Whether it's first responders or soldiers in the Middle East, when the order comes for a bomb squad to deploy, they've got to do it quickly. Which isn't easy, considering that they wear full bomb suits and carry hundreds of pounds of detection equipment. If you could limit the weight and processing time of that equipment, you could make bomb squads more nimble. And if you could make them more nimble, you could save more lives.

In the past analyzing a mysterious substance often meant taking a sample from the scene back to a lab—a time-consuming

and possibly dangerous detour. Hours could be spent determining if a substance were an explosive, a deadly toxin, or simply harmless chemicals. But this year **Thermo Fisher Scientific** introduced Gemini, a first-of-its-kind handheld spectrometer that combines two separate chemical identification technologies in one lightweight unit. Raman spectroscopy, which measures the amount of light scattered by a substance, works best on semitranslucent containers, liquids, and fluorescent powders. Fourier transform infrared spectroscopy (FTIR) measures the amount of light absorbed, and works best on the other stuff: colored substances and samples that emit light. The four-pound device has an

onboard database of fourteen thousand substances and its own anvil for precisely crushing samples. That anvil can even be set to a timer, allowing operators to retreat to a safe distance. Using Gemini, bomb squads can now analyze a much larger range of substances on site. And the results are nearly immediate. —**DAN DUBNO**



The Next Generation

Young innovators who are already making a difference.

A BETTER WAY TO TRANSPORT VACCINES

ANURUDH GANESAN,
16, CLARKSBURG,
MARYLAND

When he was an infant, Anurudh Ganesan's grandparents carried him ten miles to get a vaccine. But when they arrived at the remote village in southern India, the immunizations were unusable because of improper refrigeration. Ganesan knows how fortunate he was to have survived that experience. But many kids aren't as lucky. World-wide, 1.5 million children die every year from diseases that could have been prevented. That inspired Ganesan to create the Vaxxwagon, a refrigerated transportation unit for vaccines powered by its own wheels.

While trucks and airplanes with reliable refrigeration carry vaccines from manufacturers to distributors to clinics, transportation to remote villages often happens on foot or bicycle while using ice packs. That poses a lot of problems. "In order to make ice you basically need water and electricity, both of which are precious resources in these developing countries," Ganesan says. "Over a billion people don't have access to electricity, much less to make ice."

The Vaxxwagon is a cart with a modified water cooler attached to it. When the cart's wheels turn, their mechanical action generates power for a refrigeration system similar to the one inside your typical fridge. The prototype Vaxxwagon stays cold for four hours after six hours of pulling the cart at eight to ten miles per hour, and Ganesan is working on an efficiency upgrade to get twenty-two hours of refrigeration from only two hours of work. At a cost of less than a hundred dollars, the cart is affordable, and it can be pulled by almost anything, creating flexibility for users in different locations.

Ganesan's Vaxxwagon keeps vaccines cool using mechanical energy and can be powered by bike, by foot, or by camel.



ORGANIC MATTER OF THE YEAR: LEAVES

Kelly Devens of Roanoke, Virginia, and Liam Wallace and Wyatt Pontius of Sterling, Virginia, modeled their award-winning projects on leaves—though with very different goals.

	KELLY DEVENS, 17, ROANOKE, VIRGINIA	LIAM WALLACE, 17, AND WYATT PONTIUS, 17, STERLING, VIRGINIA
What is produced	Electricity	Oxygen
Main component	Piezoelectric crystals	Cyanobacteria and poly(ethylene oxide)/sodium alginate nanomesh
Come again?	Piezoelectric crystals generate electricity when they move. For example, the way tree leaves in a storm move while being pelted by raindrops.	Cyanobacteria sustain themselves through photosynthesis. Two billion years ago the oxygen they expelled created the atmosphere that now lets us breathe.
Explain the leaf, though	Devens built a tree with a PVC trunk and branches, 3D-printed leaves, and piezoelectric stems. When hit by water, the leaves get pushed around, causing the stems to move and generate electricity.	Pontius and Wallace developed a super-tiny mesh and embedded cyanobacteria inside it to create a leaf. Their leaf was about 50 percent more efficient than the spinach they used as a control.
Where it would be used	On the roof	On Mars
What's next	Devens is going to run further experiments to find the best design for a tree with lots of branches. Once it reaches maximum output and efficiency, she hopes the invention can be integrated into a home's rain gutter and downspout.	Wallace wants to see if the leaves can be used to oxygenate water sources, while Pontius is going to try using a similar process to make leaves that produce glucose, for use as a food source.



A WAY TO KEEP DUST OFF THE MARS ROVER

ASHWIN DATTA,
16, HILLSBORO,
OREGON



Among Ashwin Datta's favorite science-fiction movies are those of the

Back to the Future trilogy. In one of the films' most famous scenes, Marty and Doc Brown use a lightning bolt to supply the voltage they need to make their world-changing invention work. Datta has done something similar. He designed a device that uses jolts of electricity to clear particles off sensitive surfaces—like the camera of the Mars rover Curiosity, for which sticky red dust presented a major challenge. The prototype worked but needed more power. Watching *Cops* with his family one night, Datta had a stroke of inspiration. He bought a low-current stun gun, hooked it up to his device, and blasted the dust off his test lens. He wants his invention on the next Mars rover, launching in 2020.

SMARTER DRONES

MIHIR GARIMELLA,
16, PITTSBURGH



Last year Mihir Garimella won the Google Science Fair's computer sci-

ence award for FlyBot, a drone with a navigation system inspired by fruit flies. This year Garimella expanded the project in a big way, developing two new drone technologies based on animal savvy.

His obstacle-detection technology, inspired in part by bird vision, uses edge detection and a single conventional camera to map a space in 3D. This is how bird brains develop spatial awareness with eyes that point in opposite directions. "Birds have already solved this problem of getting information about a 3D world with

2D images," Garimella says, "Drawing from them is the natural thing to do." Garimella's other new technology is modeled on the way flies use their senses selectively to find food. Many search technologies try to find a subject's precise location, but his saves processing power by focusing on simply getting closer, ignoring data from sensors that can't help achieve that goal.

Here's how it worked in a test where the goal was to locate a fire: From afar, fire often can't be seen or felt, so the drone used its smoke detector to choose where to look first. Getting closer, it started checking its camera for red or yellow. As it zeroed in, its temperature sensor offered maximal precision. This strategy could be used with different types of sensors to find other things, like people trapped in rubble.

So far Garimella has hacked his own electronics and software onto existing products. Now he's designing his own, and he thinks he can get the cost down to around \$200—cheap enough to be used in impoverished areas.

A BETTER LITHIUM-SULFUR BATTERY

KATHY LIU,
16, SALT LAKE CITY



Lithium-sulfur batteries could deliver higher energy densities than lithium-

ion batteries, favored by companies like Tesla, but they still have issues to work out. Scientists have been looking for ways to keep the batteries' electrolytes from dissolving their sulfur compounds, which reduces their capacity. Kathy Liu's solution is to sequester the sulfur in a molecular cage made of glucose. Glucose is effective, and also economical: because glucose and sulfur have compatible melting points, they're easy to combine, and because glucose is an

FASTER LUNG ANALYSIS

MAYA VARMA, 17, SAN JOSE,
CALIFORNIA



Diagnostic spirometers—machines that analyze lung health after patients blow into them—cost hundreds of dollars. Maya Varma used 3D printing, electrical engineering, and an app to build one for under \$35.

THE APP
The data is used to calculate several key measures of lung capacity and flow rate. Along with basic patient information, these measures allow Varma's system to diagnose COPD, asthma, emphysema, chronic bronchitis, and restrictive lung disease with remarkable accuracy.

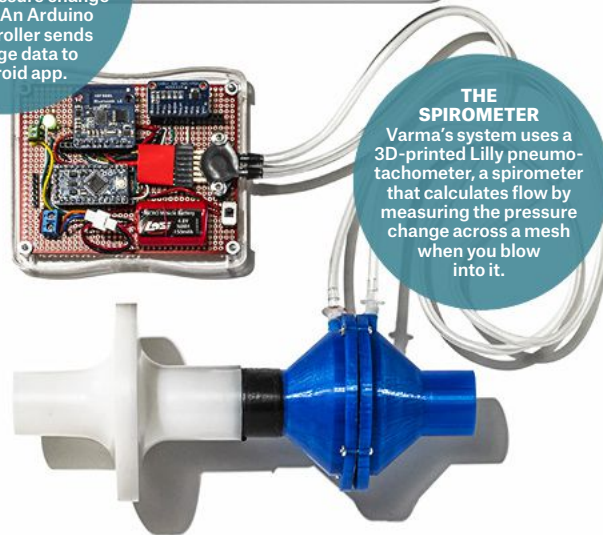
THE ELECTRONICS

Aquarium tubing connects the spirometer to a pressure sensor that converts the pressure change to voltage. An Arduino microcontroller sends the voltage data to an Android app.



THE SPIROMETER

Varma's system uses a 3D-printed Lilly pneumotachometer, a spirometer that calculates flow by measuring the pressure change across a mesh when you blow into it.



abundant, naturally occurring sugar, it's sustainable.

TRACING THE BRAIN

CHRISTOPHER LU,
17, SAN DIEGO



In his own words: "Last summer I got an internship reconstructing neurons at the Salk Institute for Biological Studies in La Jolla, California. A special machine cuts brain tissue into thirty-nanometer-thick slices and takes a picture of each one, so each chunk of brain ends up like a loaf of bread with sixteen hundred slices. We were using

the cross sections to create 3D images of the neurons. I thought it would be really cool, but it turned out to be really boring. I had to trace the outlines of neurons by hand for eight hours every day.

"It seemed like something a machine should be able to do, so I thought about everything I knew about neurons, then tried to write it in programming form. I know neurons are round and don't usually have sharp edges. I know what shades of gray they are in our black and white pictures. I tried to give the computer that understanding of neurons too.

"Now I can tell the program where to start on a neuron, and it can figure out which way the

edge goes from there. I've tested it on some of the sets I traced, and the error rates are less than 1 percent. It took me a month and a half to trace one neuron, but my program takes only forty-four minutes.

"I'm working on adapting it to be compatible with the other programs we use at the lab. Ideally, I'd like to be able to share it with researchers on the BRAIN Initiative, the national effort to map the brain's functions.

"This summer I worked with the same mentor. Sometimes she told me to stop tracing and work on the software."

BLOOD-CLOT TREATMENT

DEENA MOUSA,
16, TROY, NEW YORK



Ninety percent of the soldiers who died of potentially survivable wounds in the first ten years of fighting in Iraq and Afghanistan died because of uncontrolled blood loss. Clotting occurs in three steps, but most treatments target only one. Deena Mousa developed a mixture of compounds called Hemostat V-Seal to accelerate all three. Conventional treatments require ten to eleven minutes to stop bleeding, but Hemostat V-Seal takes three to four. Mousa has applied for a patent and is taking preliminary steps toward commercial availability.

ANTIVIRUS SOFTWARE BASED ON BITCOIN

CHARLES NOYES,
16, VILLA PARK,
CALIFORNIA



In his own words: "If I said to you, 'Trust me to hold \$1,000 for you until you ask me to give it back,' you probably would say no. And I wouldn't blame you. But if there's one million people who will actively watch to make sure that I'm holding it for you, you will probably have a little

more confidence in me. That's the big idea behind Bitcoin. It's called the blockchain, and it's a method for everyone to communicate with each other. My project, BitAV, applies this idea to antivirus protection. When you download the software, it starts analyzing your computer and compiling anonymous reports. It notices what problems are occurring, and every computer on the network learns from these reports. With a million eyes, even if some of those eyes are malicious, the odds that you'll get someone who calls out a vulnerability or says an attack happened is much higher.

"The crucial part is that it's something everyone works on together, as opposed to paying McAfee or Norton or one of those antivirus companies to protect your computer. Companies like that were at the Intel International Science and Engineering Fair and were interested in my project. They'd come by and I'd start talking about it, and they'd realize this is totally counter to their business model. Then they'd leave.

"I'm going to keep working on applications of the Bitcoin protocol for stuff like this. This is the moonshot theory, but I honestly think the blockchain is the most important invention since the Internet. I don't think there's anything that's going to propel us forward faster."

ENERGY FROM THE AIR

VIKRAM PANDIAN,
14, ALLENTOWN,
PENNSYLVANIA



A fourth grade book report on Nikola Tesla introduced Vikram Pandian to the idea of getting energy through the air. Today researchers are learning to use energy from the radio frequency waves all around us that are in the form of cell, Wi-Fi, TV, and radio signals. But to know how effective that kind of system might be, scientists need to know where RF energy is available. Pandian built an

Arduino-powered device that measures ambient RF energy and an app to create heat maps of it. He envisions his device being incorporated into cars or mobile devices to crowdsource a global RF energy map.

EARLIER ALZHEIMER'S DETECTION

PRAVIN RAVISHANKER,
15, SUNNYVALE,
CALIFORNIA



Despite being the sixth leading cause of death in the U.S., Alzheimer's cannot be prevented and is currently diagnosed in only 45 percent of affected patients. Pravin Ravishanker wants to do better. The fifteen-year-old created a software

tool, ALZCan, that combines neuroscience, statistics, and computer programming to diagnose Alzheimer's—before its onset. Using machine-learning techniques and data from the Alzheimer's Disease Neuroimaging Initiative, Ravishanker trained ALZCan to find biological indicators of the disease. He was able to predict the onset of mild cognitive impairment and Alzheimer's one year in advance with 68 percent accuracy and two years in advance with 55 percent accuracy. Given more patient data to further refine ALZCan's predictions, Ravishanker expects those numbers to go up—and us to have a better chance of figuring out how to stop Alzheimer's.



BREAKTHROUGH HIGH

GREENWICH HIGH SCHOOL,
GREENWICH, CONNECTICUT

If science fairs were sport, Greenwich High would be the New York Yankees. In the ten years that Andrew Bramante has been teaching the honors independent science research class there, Greenwich has sent at least one student each year to the Intel International Science and Engineering Fair. This year it sent five.

Two of those students caught our attention. Junior **Olivia Hallisey** (above, left), seventeen, saw how Ebola devastated Africa and created a new test to detect the disease before symptoms develop. By using color change to indicate a positive result, it can be universally understood, and it will cost 97 percent less than existing options. It also doesn't require refrigeration, a handicap of the current tests.

Junior **Margaret Cirino** (above, right), sixteen, developed a water-soluble transporter for medication in your body. It's cornstarch-based, but engineered to have magnetic properties so an external magnet the size of the ones on your refrigerator can guide it to a specific part of the body. For treatments like chemotherapy, this could help reduce harmful side effects.

Bramante says his students are successful because he treats them like adults: "I'm training colleagues, not teaching students."

monsters

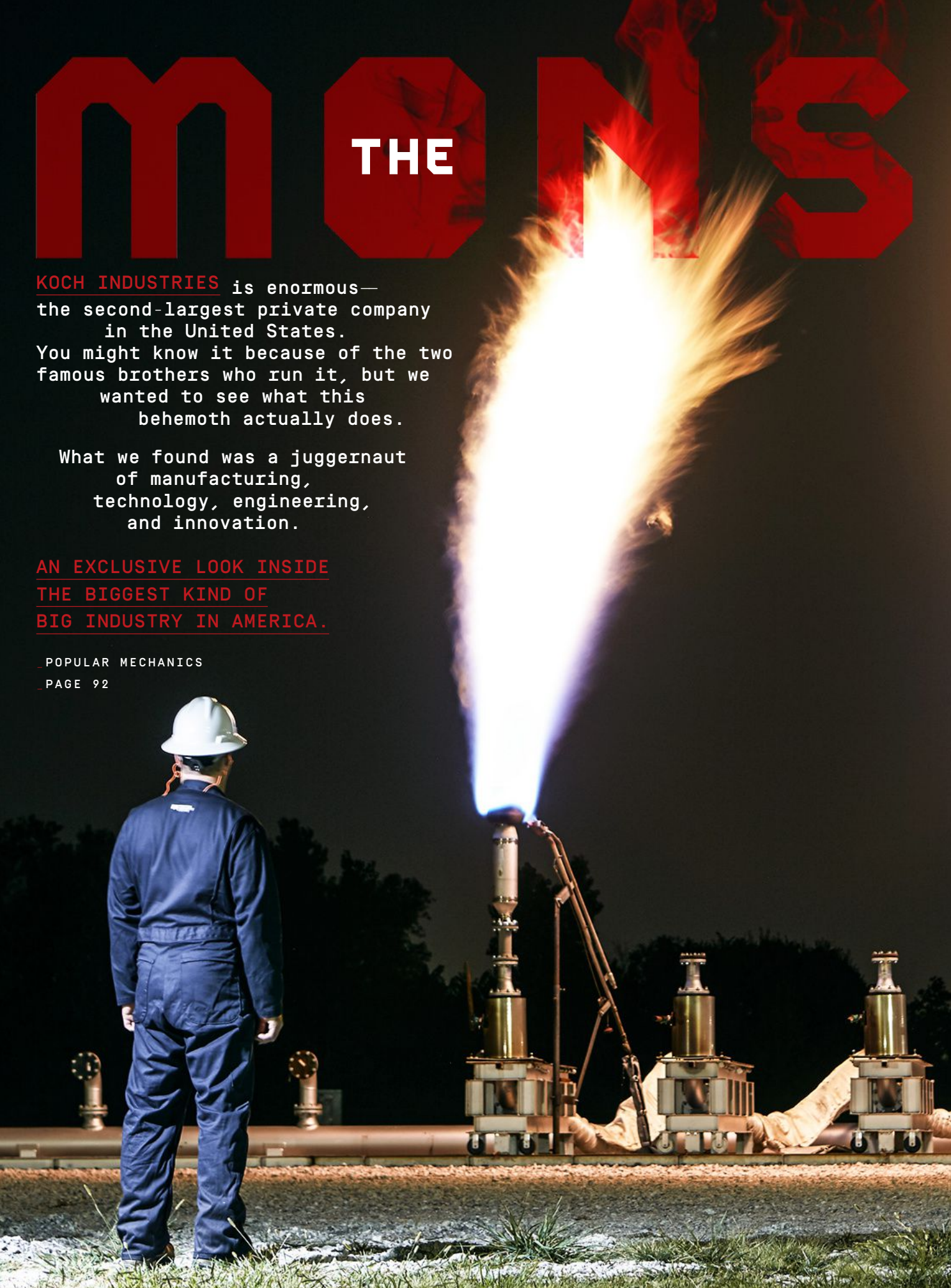
KOCH INDUSTRIES is enormous—the second-largest private company in the United States. You might know it because of the two famous brothers who run it, but we wanted to see what this behemoth actually does.

What we found was a juggernaut of manufacturing, technology, engineering, and innovation.

AN EXCLUSIVE LOOK INSIDE
THE BIGGEST KIND OF
BIG INDUSTRY IN AMERICA.

POPULAR MECHANICS

PAGE 92



TER

By **MICHAEL J. MOONEY**

Photographs by **REED YOUNG**



A nighttime test of combustion flares at a
Koch facility in Tulsa, Oklahoma.

—This is an adventure story.

It is an expedition into the heart of a huge and uniquely American industrial enterprise, its sweeping operations and its complex daily mechanics. It is also a rare exploration of what lies beneath and empowers the broad social influence of its owners, David and Charles Koch, the business and political titans who have helped reshape American politics.

People who don't agree with the Koch brothers see them as pernicious, because their views are often extreme and because they have so much money with which to try to further those views. People who agree with them see them as saviors for the same reasons. Both groups care because of the Kochs' enormous fortune, which is estimated to be \$100 billion. But few outside business circles know where that fortune comes from or how pervasive their company's industrial influence is on our everyday lives.

Koch Industries is a massive conglomerate—Charles is the CEO, David the executive vice president. What began as a petroleum processor when their father started it in 1940 is now considered by *Forbes* to be the second-largest private company by revenue in the United States, bringing in more than \$115 billion annually from businesses that touch virtually every industry and every part of American life. Koch and its subsidiaries make the fibers in your carpet (Stainmaster), the toilet paper in your bathroom (Angel Soft), the stretch material in your jeans and yoga pants (Lycra). They make the connectors in your phone (Molex), the glass in your windows (Guardian), fertilizers used to grow your grocery-store-bought fruit and vegetables (Koch Agronomic Services), and pipelines that deliver the gas and petrochemicals from which many of those things are themselves made. The company employs more than a hundred thousand people in sixty countries, including close to sixty thousand in the United States. Koch is the biggest kind of big industry.

But, of course, that's not what the name Koch is known for by most people. Around 2003 the Koch brothers started to give money to politicians. Not just for the reasons corporations usually do, donating to the campaigns of candidates who they hope will vote in such a way that furthers the interests of their company. That was part of it, of course. But the Koch brothers also began giving to people who shared their personal views on social issues, everything from climate change (which they think is overblown) to health care (which they think the government should stay out of). Their beneficiaries have been almost all Republican, and the Kochs now hold a private conference each year that has become an essential stop for any Republican hoping to win their blessing and financial support (except Donald Trump, who wasn't invited to the event this past summer). Their contributions to political candidates, many of which are made through their super PAC (the Freedom Partners Action Fund), reach into the millions.

The breathtaking, throbbing industrial machine that generates that money—the smoke and fire and gas and oil, workers grinding and sweating and punching in and punching out, plastic and chemicals and paper and trees, pollution and

purification, assembly lines stamping out the stuff that makes daily life in this country possible—is what this story is about. It is a world usually closed to public view, and entry into it was the product of persistent requests by this magazine and long negotiations. In the end the company—no doubt in an effort to burnish its public image—allowed *Popular Mechanics* unprecedented access to facilities in Kansas, Nebraska, Iowa, Louisiana, and Oklahoma. (They did not, however, initially allow access to Charles Koch, going so far as to reschedule one of his lunches to make sure we didn't cross paths in the hall. They later did grant an interview with him, in support of a book he has coming out this month. See page 98.) When they eventually allowed us into the Koch world, they showed us a wide range of what they do. But the seven facilities we visited are still only a part of Koch Industries. As a private company, it doesn't divulge information about its business structure, so it's hard to know precisely how these fit into the whole. According to Koch Industries, that whole includes “companies involved in refining, chemicals, biofuels, and ingredients; forest and consumer products; fertilizers; polymers and fibers; process and pollution control equipment and technologies; electronic components; commodity trading; minerals; energy; ranching; glass; and investments.” We didn't see all, but we saw a lot.



The first stop, a logical one, was Koch headquarters in Wichita. A summer day, the cafeteria buzzing. There are lines for sandwiches, salads, pizza, and something called Latin bowls, and a wall full of giant flat-screen TVs showing at least six different channels. The campus itself: nine long buildings of granite and glass housing thirty-six hundred employees centered on a 100-acre plot adjacent to a middle school and a program for children with special needs. (Koch donated a total of 55 acres of land.) There are on-site dry-cleaning drops, a company store that sells just about anything a business traveler could need—from golf shirts to packed lunches to gifts for the kids at home—and an algorithm-based elevator system designed to move the thousands of workers to their respective floors with absolute maximized efficiency. The employees seem diverse: young and old, a mix of ethnicities and backgrounds



2

[1] At John Zink Hamworthy, a Koch-owned combustion company, a pressure tank stores steam at 450 psi. The steam feeds flares to enhance the mix of gas and air for smokeless combustion, minimizing emissions. [2] A welder assembles a steam-assisted flare. [3] An engineer pauses in front of the air inlet on one of two 350-hp fans used to test air-assisted flares mounted on the stack in the background. The fans supply up to 6,000 cubic feet of air per second to the flare.



3

all eating their Latin bowls together. Then they get back to work, attending to the management of finances, the routines of administration, the delicate calculation of public relations, all of it with a focus on relentlessly making the company bigger.

Growth is the most fundamental part of the corporate culture. Short of actually releasing numbers, Koch's CFO has said its growth rate of at least 12 percent allows it to double its earnings, on average, every six years. Accountants are told they essentially have no budgetary limitations. If an investment idea is sound, they'll make it, regardless of scale. If there is a way to grow sustainably, they will, without apology. "If you don't think of a way to make your own job obsolete," one plant manager said, "someone, somewhere, will."

PIPES FOR GAS AND OIL

McPherson, Kansas

An hour from Wichita lies Invista, the fiber and polymer company Koch bought in 2004 and which alone employs ten thousand people in more than twenty countries. At one end of the factory is a four-by-four-by-four cardboard box filled with small, shiny black pellets connected to a high-powered

vacuum. A thousand feet away the pellets have become a fifth of a mile of laser-engraved, bendable pipe, which is marketed under the name Raptor. It looks hard, but it's made of nylon. It's actually called nylon 6,6, a multiuse nylon that can withstand temperatures up to 200 degrees and pressure up to 500 pounds per square inch. Nylon 6,6 is lighter and cheaper than steel and just as flexible, but far stronger than polyethylene—those being the other two materials such pipes are traditionally made from. Nylon 6,6 is what they call a game changer.

At that end of the main factory, where the pipeline comes out, is a machine called a coiler. It looks like a robotic monster borrowed from the set of a Hollywood blockbuster—twice as tall as the men operating it, with eight yellow pinching claws powerful enough to pull you apart in seconds.

The complicated, intellectual-property-protected, true technological innovation happens closer to the cardboard box, where the heated nylon pellets are shaped into the dense pipe. But the flexibility of the pipeline, the fact that it can be coiled by that monster without breaking, is what makes this factory special. It means more than a mile of coiled pipeline can fit on the back of a truck—nearly twice as much as the traditional steel alternatives. The coiler is mesmerizing and terrifying. It winds through the pipeline with smooth, cool proficiency.

On the ride out to McPherson, an Invista engineer and a Raptor salesman explained some of the durability tests they've done in the half decade since they first started exploring the concept of nylon pipeline. There are temperature tests, in which they try to simulate years under the baking west Texas sun or in the bitter frozen hills of North Dakota in deep winter. There are fire tests, wind tests, and, because the pipe is meant to lie directly on the ground, tests to see if it can endure thousands of pounds of cattle marching back and forth across it. "It's not for the faint of heart or the pleated of pants," says a gravelly voice in a video on the company's website, calling the nylon 6,6 material they use "engineering black magic."

After the coiler turns and grips and ties off more than a mile of pipeline—which takes a matter of minutes—workers perform the pressurized water test that they put a segment of each shipment through before sending it out to a customer. "We want to know everything about the product before it leaves the factory," Glenn Munshaw, the engineer, says. "That includes the specific limits of each piece we produce."

Greg Standifer, the salesman, places his cellphone on top of a steel box with thick glass windows—the phone's camera is facing down into the box so it can record the inside. "You're gonna love this," he says with a grin. "I like to try to get it on video."

A piece of the black pipe is strapped inside the box, which is

connected to a monitor streaming data. This is a pressure test—the pressure inside the box can be controlled from the outside. The test begins and the box emits a low roar. As the sound gets louder—like the loudest dishwasher you've ever heard—everyone takes a step back. The numbers push past the limits for which this particular grade of pipe is approved. They double, then triple. The anticipation is excruciating. Then, after the internal pressure pushes past five times the recommended limit, there's an eruptive, cannon-sized pop—a bang so startling that several of those present jump, even though everyone knew it was coming.

Standifer rushes to get his phone so he can watch it again.

BIODIESEL

Beatrice, Nebraska

They talk about it like it's a caged beast. As in: "You can give it so many different feedstocks and it still performs so well for so long," or "We learned that you can, in fact, kill it under just the right circumstances."

Nine men sit around a conference table next to a biodiesel plant far from anywhere you might accidentally wander. This was the site of a plant that was never completed, aban-

[1] A crane in Georgia-Pacific's wood yard. Logs are chipped and used for papermaking, and bark is stripped and burned to make steam, which generates electricity for the mill. [2] This is not a tiny man. Those are huge rolls of paper ready for repulping. [3] A massive conveyor moves wood chips for papermaking. Chips are broken down into fiber and lignin, a tree's natural glue, which is used as fuel. [4] Laser-guided vehicles carry Quilted Northern to waiting trucks. [5] At the converting station, rolls of single-ply toilet paper will be joined together to create two-ply.



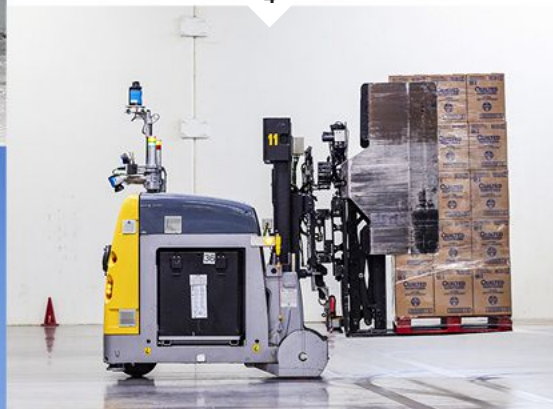
2



done in 2007, and sold by the bank to a joint venture of Koch-owned Flint Hills Resources. The men—a mix of engineers, venture managers, plant and project managers, and money guys—are talking about the more than \$100 million the company has since put into this project, which included building a small pilot plant outside Dallas and the retrofitting of this facility. When they talk about the beast, they're referring to the catalyst they say could be the future of biodiesel energy.

Not that most people would understand much even if the men could talk in detail about the process, and for proprietary reasons they speak in loose metaphors anyway. Like when they say the catalyst would look to the layperson like a strange piece of rice you wouldn't want to explain to airport security. This particular catalyst, when pretreated in just the right way, can convert any number of feedstocks, plant-based or animal fat, into high-powered biodiesel. They say this site, scheduled to open around the time of publication, can turn any of it into usable energy on a huge scale, energy that could light cities or power bullet trains. The plant is forty times the size of the Dallas pilot plant, sufficient to start making and selling 50 million gallons of biodiesel per year.

4



5

CHARLES KOCH

BY
Ryan
D'Agostino

THE POPULAR MECHANICS INTERVIEW



After first declining to make him available, Koch Industries eventually granted us an interview with the company's CEO in conjunction with the publication of his new management book, *Good Profit* (October). When he spoke, he was recovering from foot surgery and was a little "groggy" but in good spirits. The following is an edited version of the conversation. You can read a longer version at popularmechanics.com/Koch-industries.

Popular Mechanics: The Koch name today is known more for politics than industry. Does that bother you?

Charles Koch: It goes with the territory. I've been interested in the ideas of freedom and prosperity and stuff for over fifty years, but we really started in the political side in '03 when we began to build this seminar network. It was to oppose all the destructive things we thought the Bush administration was doing. Of course, when you get into politics, people in power feel threatened. They try to stigmatize and demonize you to discredit you. We knew that would be coming. But we have been fortunate to have a great many wonderful people build what we think is an outstanding company. We have over a hundred thousand employees in sixty countries and close to sixty thousand American employees.

PM: Industry creates pollution. What does Koch do to mitigate that?

CK: That's one of the biggest misconceptions about us. Our opponents say we're one of the biggest polluters. And since we're one of the biggest manufacturers in the country, we are going to have among the highest emissions. When you're making automobile components and clothing, producing food, creating housing, transportation, communications, you name it, there are by-products. Do you want to go back to living in caves

and having nothing? If not, I would think you would want the companies doing the manufacturing to be the ones who do it with the lowest emissions. So when we evaluate whether we're going to buy a plant or a business, if we don't think we can greatly improve the safety and environment, we don't acquire it.

In refining, our emissions, I think, are about a third less than the average per unit of production. In the EPA's Toxic Release report in 2015 they ranked Koch Industries the best U.S. company for implementing pollution-preventative initiatives. Number one. It doesn't fit the stereotype of number-one polluter.

It's a business decision. If a community's going to have one plant in their area, we want them to want us. If we have a customer supplier, we want them to prefer us. So we try to perform in a way that we are preferred. Do we always accomplish that? No. But that's our goal.

PM: How would you rate the health of American industry and manufacturing right now?

CK: Just look at our growth rate—what is it, 1 or 2 percent a year? And the increase in productivity is even less than that. And that's in the face of tremendous improvements in technology. We could have the greatest boom in history. I think it's because of misguided policies by both political parties—out-of-control spending and the crony-

ists who are advocating corporate welfare, where businesses don't put their emphasis on competing by producing and innovating to create better products and services, but by getting subsidies, mandates, and special privileges.

PM: What about your outsize financial influence on American politics? I think a lot of people wonder if you believe your views are more important than those of people or companies with less money.

CK: If we have so much influence, why do these things we oppose keep getting worse? So obviously we don't have the influence. Now, you can say, "Well you've helped elect a bunch of Republicans." Yeah well, that's because the Republicans are only taking us down the road to serfdom at seventy miles an hour and the Democrats are taking us there at a hundred miles an hour. And even when we help elect them, they vote for more boondoggles. So, influence? Yeah, I'd like to have some influence. We would support Democrats. I'm not interested in a party or politics.

PM: Describe what it feels like when you visit one of your companies and you see some sort of industrial marvel happening before your eyes.

CK: This has been my life's work, so I get very excited when I visit with the people. "Gosh, how'd you guys do this?"

An enormous crane—it took fifty-five trucks to deliver it—stands ready to lower a new piece of equipment that's coming by rail later in the week. The metal superstructure of the plant is about ten stories tall, and there are dozens of men hanging off of every level, welding. Sparks fly in every direction.

The place has come a long way since Flint Hills bought it. Michael Harris, one of the venture managers, says that at the time it looked like it was "straight out of a zombie movie." They set about adapting it for their purposes. The site itself looks like most processing plants, the kind of industrial complex you might pass daily and never think about. (Locals seem more excited about the number of jobs the plant will provide—fifty—than the significant innovations inside.) But the company says it's not just the multiple feedstock options that make this concept potentially world-changing. It's the final product. They say that the fuel it makes is cleaner, more efficient, and more versatile than any existing biodiesel. Those specifics, too, are well guarded, but Jeremy Bezdek, whose title at Flint Hills is managing director, innovation, puts it like this: "Most biodiesel looks like a nice, hoppy beer, maybe an IPA. Our product is pure, clean vodka."

TOILET PAPER

Port Hudson, Louisiana

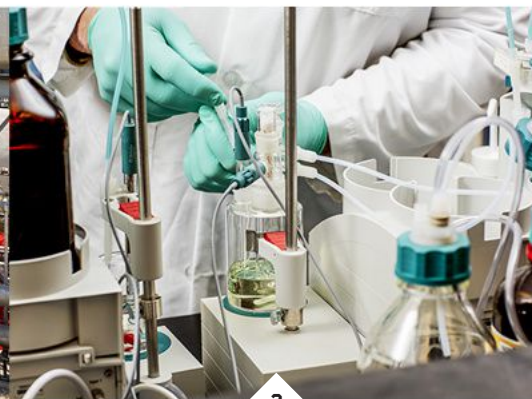
A deer runs across the road that leads to the gates of the Georgia-Pacific plant, built at least partially on a Civil War battlefield just feet from the banks of the Mississippi River. The 1,350-acre facility, surrounded by tall, lush greenery, employs nine hundred people who make Brawny paper towels, Quilted Northern toilet paper, and Spectrum printer paper. It can process 5,000 tons of wood—southern pine, gum, oaks, maples, and poplars—in a day.

The road on one side of the plant is backed up with trucks full of logs. Standing over the delivery spot, taking logs from huge piles as quickly as the trucks can dump them, is what looks like a colossal version of that arcade claw game, only in this game the claw always collects and delivers the prize, and the prize is always several tons of trees.

Each tree is stripped of its bark, which is then burned to power part of the plant. Kelvin Hill, the vice president of Port Hudson operations, says the site produces 95 percent of the energy it uses, "and we're always pushing to try and get that number higher, higher." Hill even has an idea about capturing the flammable dust particles that surround the



[1] The fatty acid methyl ester, or FAME, at the Duonix Beatrice biodiesel plant, converts feedstocks into biodiesel. [2] Samples are bottled and compared against standard biodiesels. [3] Lab technicians test samples for moisture content.



rolls” at a rate of one every 35 minutes. It takes two parent rolls to make fifty thousand individual rolls of Quilted Northern Ultra Soft & Strong Double Roll TP. (You need two because it’s two-ply.)

Most of the products leave here having never been touched by human hands. Workers refer to the largest laser-guided robots that haul products back and forth across the plant as “elephants” because they can reach 18 feet high and carry 40,000 pounds at once. The paper made here and

at G-P’s other plants will be sold under any number of brand names and generics. “We got a letter from a lady saying she was never going to buy Angel Soft again because she found out it was owned by Koch,” one employee says. “So she said she was switching to Quilted Northern. I wanted to write her back and say, ‘Ma’am, that’s perfectly okay with me.’” Each of these two brands brings in more than \$1 billion a year to Koch Industries.

ELECTRONIC COMPONENTS

Lincoln, Nebraska

This is what tomorrow looks like: Row upon row of robots pumping, turning, and pivoting with remarkable precision. Some can cut precious metals to a tenth of a millimeter in thickness. The humans at the Molex plant here in Lincoln, the ones who years ago might have been hunched over, working with their hands, now mostly monitor and aid the machines, sometimes at a ratio of one person to six or eight machines at a time. Koch purchased Molex—one of the world’s largest manufacturers of electronic connectors and components—in 2013 for around \$7 billion.

Many of the machines are making half-dollar-sized plastic parts that will become connectors or circuit protectors in phones and cars and appliances. One robot makes tiny blue plastic pieces that will later be used in the circuit boxes of cars. (Molex has contracts with many major automakers and suppliers.) The robot shapes, then cuts, then measures four pieces at a time, kicking back any individual bits of plastic that don’t meet exact specifications, and dropping the usable parts into

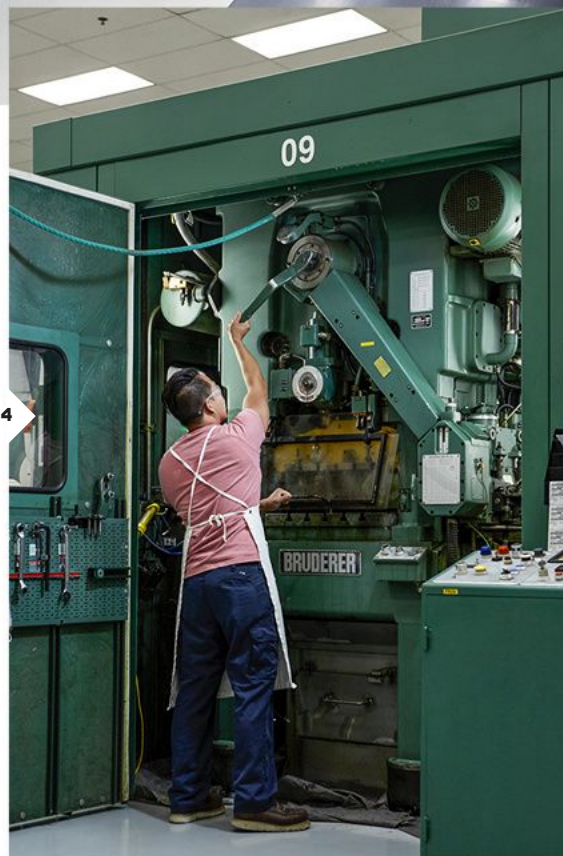
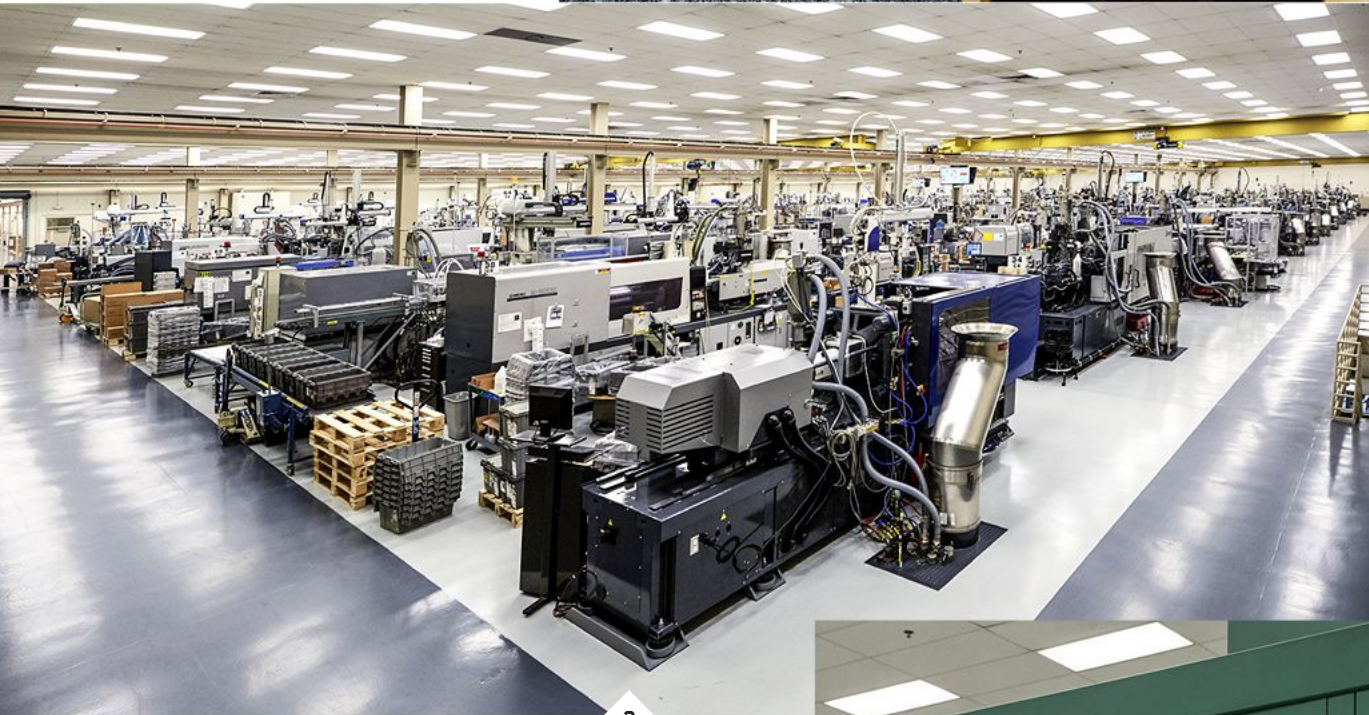
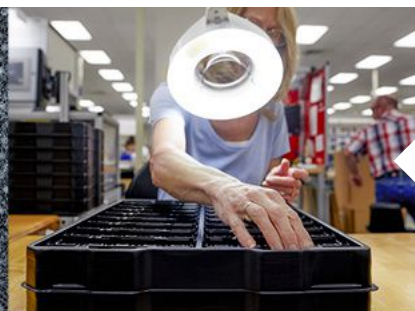
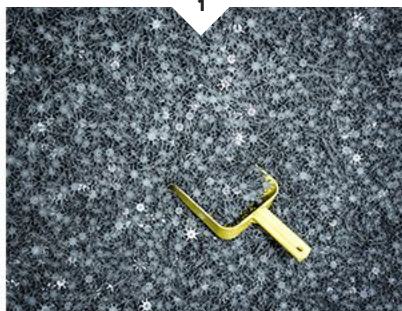
tissue machine. “We can use that power,” he says. (The virtues of this kind of market-based management, or MBM, come up at several Koch locations. MBM is a business creed that emphasizes individual performance, in which each employee is empowered to think like an entrepreneur rather than a cog. The Koch website encourages workers to come up with their own solutions to problems “rather than waiting for orders from higher-ups.”) Half of all the energy Georgia-Pacific uses, according to Koch Industries, comes from renewable sources.

Hill has worked at the Port Hudson plant for more than twenty years. He loves thinking about the way paper is produced and about all the things people don’t know about the paper they use every day. He cites a fact he knows by heart, that in the timber industry, for every tree harvested five are planted. “If we’re ever out of trees, we’re out of business,” he says.

After they’re debarked, the logs are turned into pulp. Walking around outside, the air smells a little like boiling broccoli. Making paper takes a lot of water—millions of gallons a day at Port Hudson, typical of a plant this size—one of the reasons that paper mills are usually close to rivers. At every step, the wood—and then the paper—is hit with a precise amount of water, which helps break down the fibers and keep the products pliable. There are grates everywhere to recapture the water for reuse or to be treated and returned to the ground.

Inside each of the buildings is a series of machines, some more than three stories tall and longer than a football field. One of the toilet-paper machines spins out huge “parent

[1] At Molex, plastic resin scraps, called runners, are captured and reground to be reused in the molding process. Molex recycles more than 90 percent of its scrap. [2] A visual quality inspection on a component of a transmission control unit. [3] Precision injection molding machines produce plastic connector housings, many for use in autos. [4] High-speed stamping machines use dies to stamp terminals out of metals that include brass or copper alloys, and workers can switch out the dies needed for line changes in just a few minutes.



a box ready to ship.

To compete against the cheap cost of labor in China, factories like this have to produce twenty times as much as a Chinese factory of the same size, one manager said. The factory in Lincoln produces more than two billion individual pieces every month. There are so many plastic pieces for so many different products being produced at any given time that it is nearly impossible for a manager to walk over to any one machine and know exactly what it's making.

If you could bisect the factory, you'd see two floors of machines working in unison. Upstairs is the pressing, the cutting, the shaping, full of tall, bright, spotlessly white rooms, each with the rows of robots. There are flat-screen monitors in the air showing which machines are producing the fastest. When one goes down for repair—which can cost thousands of dollars an hour, depending on the machine—it shows up in red on the board, like an injured athlete. Each robot upstairs has a corresponding machine downstairs that pumps up everything from power to polymers. There are wide tubs full of tiny pieces of plastic and reels of copper and silver and even some gold slowly unwinding. When the machine upstairs is done, defective pieces and excess material are sent back down, back into the grind. “Ninety percent of our scrap plastic resin is recycled in one way or another,” says Steve Norton, the director of operations at Molex in Lincoln. “And 100 percent of our metal scrap, cardboard, paper, batteries, and electronics.”

FIRE

Tulsa, Oklahoma

At first the small rocks on the ground start to jump, spontaneously popping a few inches into the air one after another. Nine combustion flares are blasting great flames into the sky, reaching higher and higher, as if a control knob on a humongous gas stove is being steadily turned up. As the flame pushes past 1,400 degrees, the rocks start jumping around like popcorn. The flames grow higher, the temperature approaches 3,000 degrees, and though you are standing more than two hundred feet away, protected by a neon-orange, flame-retardant coat and shielding your face with heavy, industrial gloves, the heat is starting to suck the moisture from your eyes.

This is all happening on a gravel lot behind an unremarkable two-story office building not far from the airport in Tulsa, Oklahoma. It's the headquarters of John Zink Hamworthy, a combustion company that makes industrial burners and flares that can shoot flames eighty to a hundred feet into the air. (The company is often required to notify the airport before conducting tests.) A flare is essentially a safety device that uses combustion to convert flammable or otherwise dangerous gases or liquids into harmless compounds. They're used at landfills to neutralize methane gas, and at liquefied natural gas plants, where they can burn off high volumes of gas in an emergency, to prevent damage to people, the plant itself, and whatever else is nearby. A burner, meanwhile, uses combustion as energy. It can generate steam in a boiler or the heat needed to make food or pharmaceuticals or any number of other products. Burners like the ones at Zink are designed to minimize pollution usually associated with combustion sources, and the combustion flares and burners made here are hotter and more efficient than traditional flares and scrubbers, which often generate their own off-gases, and they help reduce CO₂ emissions.

As Americans we surround ourselves with material goods, some of which we keep forever, some of which we discard almost immediately. We don't often consider how a lot of things are made—things like Bluetooth headsets or office carpet or printer paper—or what goes into them. But the somebody that makes a lot of this stuff is Koch Industries. Pollution is the toxic, potentially lethal cost of doing the business we do—and of enjoying the life most of us enjoy. Eventually a lot of by-products end up here, in the flame. Not literally here in Tulsa. But often, in a variety of industries, the emissions will run through a burner born here, on the gravel lots at John Zink Hamworthy's combustion testing facility. Here, as many of those by-products as possible are burned away. Here, the air is cleaned, most of the toxic chemicals incinerated in the searing heat of the developed world.

The power of the flames stops you. You just stand there watching their power, wondering a little what they're for and wondering a little how we got here. The soaring fireball is big and hard to define. It's simultaneously awe-inspiring and dangerous. And its growth, its rapid spread from the ground into the sky, is a by-product of our very lives. America, by and large, for better or worse, pushes relentlessly ahead. There are by-products and emissions and pollutants, and we do our best to deal with those, but the pushing ahead always wins.

Koch is responsible for an enormous amount of pollution—with the sheer scale of their operations, it's inevitable—but they are also responsible for technology that reduces the amount of pollution. Zink is one of the only manufacturers in its field to actually stay ahead of EPA standards, because it knows those standards will always change. They do this not because it might be noble or altruistic, but because, as the man at the paper mill in Port Hudson said, if they don't have trees, they're out of business.

The flames serve both to propel industry forward and to incinerate the terrible by-products that industry creates. The inside of the consummate American business is a giant blazing fireball that allows us to live the way we have chosen to live, and when you see it, you stare and stare until, eventually, you have to look away.



[5] At nylon-pipe-maker Invista, the extrusion process converts molten polymer into hard pipes; the startup process creates extrudate, or "plop," as the extruder warms up. [6] Glenn Munshaw led the team that built the industry's first nylon 6,6 pipe extrusion plant. [7] Operators prepare 1,000-foot coils of nylon pipe for shipping.



Don't Get Burned

Dangerous and potentially deadly counterfeit products, from extension cords to cell phones, are purchased every day.

Take this extension cord, for instance. If you bought it "on the cheap," you could be... well, playing with fire. Fake products are made without safety standards, and they put you and your family at risk. Stick with reputable products from trusted sources and you won't get burned.

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PROJECT



Protective suits worn by the insulation crew are individually air-conditioned.

THE COLDEST ROOM

After nearly two decades of sweaters, blankets, and constant complaints, we finally decided to fix the freezing family room.

BY PETER MARTIN

When carolers sing of Christmas, of idealized images of happy families gathered around a warm hearth, they are not singing about our hearth. For my family, Christmas over the past two decades has meant sitting on the couch in sweatshirts or huddled under blankets, wondering why a constantly burning fire was doing nothing to raise the room temperature higher than that of a Norwegian ice storm. We joke about living in an igloo, but we know they must be warmer than this.

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PROJECT

→ The house, in a Philadelphia exurb, was new when we moved in in the fall of 1996. And although it would be the first house our family didn't all live in full-time—more home base than home, with both my older sister and me in college and my younger sister two years away from graduating high school—the family room was and is a central feature. Big enough for two couches, the room has two walls of windows, 15-foot ceilings, and a fireplace. Some families may bond around the dinner table, but we bond in that room. Watching football, playing cards, trying to hide snacks from my mom, who admirably still tries to protect the carpet. It's a place of familial happiness. Unless it's winter.

In the winter the cold takes over. When you open the cabinet to get dice (we went through a strong Yahtzee phase), you feel the temperature difference on your hand. Walk by the fireplace and you'll swear the flue must be open, even though you just closed it. The draft is constant—and somehow everywhere. We tried everything we could think of to fix the freezing temperature. My dad lined the cabinets beside the fireplace with Styrofoam insulation. Didn't help. We duct-taped the French doors that lead to the screened-in porch to stop the warm air from escaping. Nothing. We lined the recessed lights with Saran wrap. One year, after we'd stopped caring about aesthetics, apparently, I came home to find a bright red curtain hanging in the 6-foot opening between the family room and the kitchen. Later, when it was time to replace the furnace and air conditioner, we had them add air-return ducts to just that room, hoping that it would pull the cold air out. That had to do something, we figured. Like everything else, it didn't. The room was still cold.

This year we gave up. We got help. In early August Lee Stoltzfus of Foam-Tech Insulation Service in Gordonville, Pennsylvania, with the help of my parents, packed up everything from the mantel and bookshelves—including our 1986 edition of the World Book Encyclopedia, probably the first time it's been touched since we moved in—covered the room in plastic, pushed all the furniture away from the basement walls below the family room, and got to work.

THE FIREPLACE

A lot of the trouble in the family room starts with the fireplace, Stoltzfus said,



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INSULATION

Clockwise from right: Foam was added to the uninsulated basement walls; an infrared sensor found air leaks; the uninsulated chimney exhaust; and the family room, prepped for work.

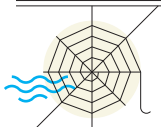


which was apparently never properly insulated. Fireplaces should have a drafting system. As the smoke and heat come up through the chimney, that air is replaced from the outside and drawn back to the fireplace, creating a circular draft. Installation requires a 2-inch gap around the pipe that runs up from the fireplace, but ours had nothing like that. It was simply open space. Cool air was flowing back into the house, and, instead of going into the fireplace to be heated and released outside, it was going into the bookshelves and then out into the family room.

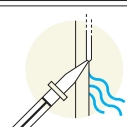
Stoltzfus and his crew fixed this by putting 2-inch fire-resistant ceramic insulation around the chimney. They wrapped that in a second layer of insulation that acted as a spacer. After

HOW TO IMPROVE YOUR HOME'S TEMPERATURE EFFICIENCY

BY LEE STOLTZFUS, FOAM-TECH INSULATION SERVICE



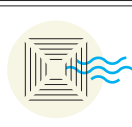
Look for spiderwebs. My colleague Mike Musser says the easiest way to find leaks is to look for cobwebs. Spiders spin their webs where there is air movement. If you see webs, you have leaks.



Get a caulk gun. As much as 40 percent of a home's energy is lost through poorly sealed doors and windows. Make sure all of yours are done right.



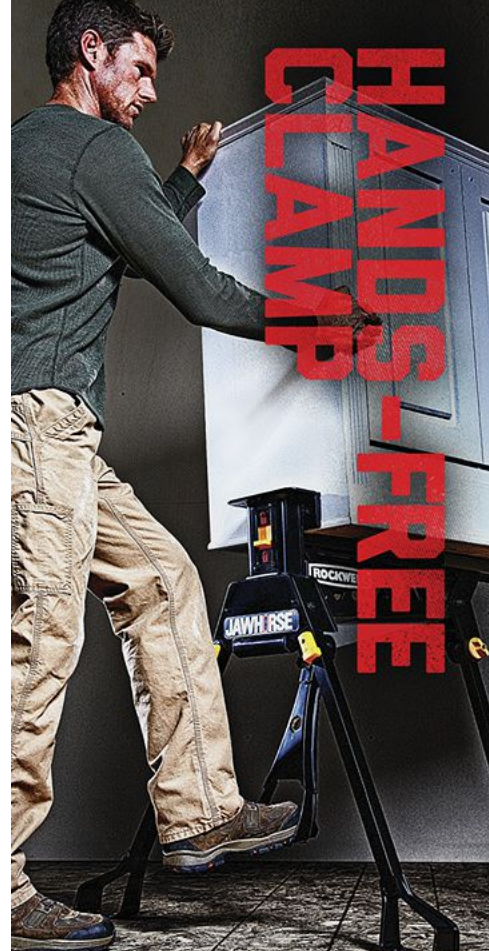
Check the lights. If you take the plate off the inside of a recessed light or a light on your porch and you can feel a draft, stick some closed-cell foam in there to block it.



Run the exhaust fan longer than you may want to. It won't help with efficiency, but if your system doesn't handle moisture well, 30 minutes after showers will avoid extra condensation.



Get an auditor. If you're really concerned, an energy auditor can give you a snapshot of your home's issues for \$350 to \$850.



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PROJECT

spraying foam over the spacer and allowing it to expand, they removed the spacer to leave the gap—and to give us a functioning chimney draft. To further insulate the room from the chimney, they created a false wall using landscape fabric. Stretched out between the sides of the bookshelves and the fireplace, the fabric allowed them to spray 2.5 inches of 2-pound foam (with an R-value performance, or measure of insulating power, of 18) between the two structures without building a makeshift plywood wall.

THE CEILING

Stoltzfus had cut an exploratory hole in the drywall between one of the bookshelves and the fireplace. That gave him access to the ceiling, where he immediately found dark shadows of condensation on the ceiling drywall, caused by the temperature changes as air flowed through the fiberglass and around the ceiling trusses. To stop this, he pulled the fiberglass off the ceiling surface.

Stoltzfus was thrilled to find out that there was plenty of room between the ceiling and the roof. That allowed him to switch our vented system—which released the hot, moist air of the “attic” above the vaulted ceiling to the outside, and, in our poorly sealed house, caused the family room to constantly draw in cold air to replace the escaping heat—to an unvented system that he said would greatly increase the

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BACK TO THE FUTURE

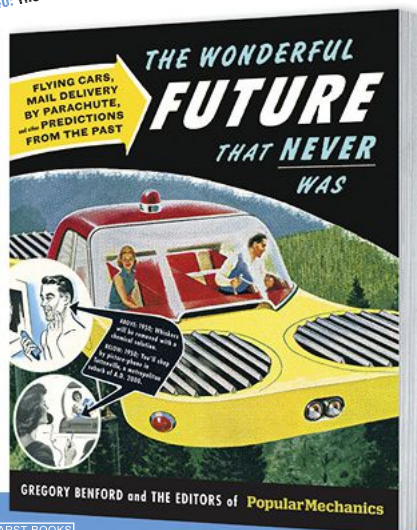


1940: The torpedo-like rail car of tomorrow ▶

OVER THE DECADES, scientists have peered into their crystal balls, envisioned the world to come...and shared their predictions with readers of *Popular Mechanics*.

What did they see? Flying ambulances. Space suits made from paper. Utopian cities with elevated sidewalks and sunken streets. Even the cure for the common cold.

In our book—a collection of these speculations with original text by Nebula winner and NASA advisor Gregory Benford—the bizarre, wildly imaginative, and (occasionally) eerily accurate *Wonderful Future That Never Was* comes to life.



WHY SPRAY FOAM?

Fiberglass insulation is a convenient, easy option, but every inch of it gets you an increase in R-value of only 3. Closed-cell spray foam adds an effective R-value of 6 to 7 per inch. Plus, spray foam leaves no gaps. One of the problems we had in the family room was the constant draft. This was partially caused by fiberglass panels that weren't completely flush. (It's been reported that gapping of 4 percent around the edges of fiberglass reduces R-value by 30 percent.) That allowed warm air to hit the cold exterior surfaces, where it cooled down, dropped back into the family room, ran across the floor and back up as it picked up heat, forming a constant loop. Since spray foam expands to fill spaces, whether they're traditional cavities or intricate details, it leaves no gaps.

AVAILABLE WHEREVER BOOKS ARE SOLD.

HEARST BOOKS

Chicago Doctor Invents *Affordable* Hearing Aid Outperforms Many Higher Priced Hearing Aids

Reported by J. Page

CHICAGO: A local board-certified Ear, Nose, and Throat (ENT) physician, Dr. S. Cherukuri, has shaken up the hearing aid industry with the invention of a medical-grade, affordable hearing aid. **This revolutionary hearing aid is designed to help millions of people with hearing loss who cannot afford—or do not wish to pay—the much higher cost of traditional hearing aids.**

"Perhaps the best quality-to-price ratio in the hearing aid industry" – Dr. Babu, Board-Certified ENT Physician

Dr. Cherukuri knew untreated hearing loss could lead to depression, social isolation, anxiety, and symptoms consistent with Alzheimer's disease. **He didn't know why hearing aids were so expensive when the prices on so many consumer electronics like TVs, DVD players, cell phones, and digital cameras had fallen.**

Since Medicare and most private insurance plans do not cover the costs of hearing aids, which can cost between \$2,000-\$6,000 for a pair, many of the doctor's patients could not afford the expense. Dr. Cherukuri's goal was to find a solution that would help with the most common types of hearing loss at an affordable price, not unlike the **"one-size-fits-most" reading glasses** available at drug stores.

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He evaluated numerous hearing devices and sound amplifiers, including those seen on television. Without fail, those were found to amplify bass/low frequencies (below 1000 Hz) and were not effective amplifying the frequencies related to the human voice.

Inspiration From a Surprising Source

The doctor's inspiration to defeat the powers-that-be that kept inexpensive hearing aids out of the hands of the public actually came from a cell phone he had just purchased. **"I felt that if someone could develop an affordable device like an iPhone® for about \$200 that could do all sorts of things, I could create a hearing aid at a similar price."**

Affordable Hearing Aid With Superb Performance

The high cost of hearing aids is a result of layers of middlemen and expensive unnecessary features. Dr. Cherukuri concluded that it would be possible to develop a medical-grade hearing aid without sacrificing the quality of components. The result is the **MDHearingAid PRO**, well under \$200 each when buying a pair. **It has been declared to be the best low-cost hearing aid that amplifies the range of sounds associated with the human voice without overly amplifying background noise.**

Tested By Leading Doctors and Audiologists

The **MDHearingAid PRO** has been rigorously tested by leading ENT physicians and audiologists who have unanimously agreed that the **sound quality and output in many cases exceeds more expensive hearing aids.**

DOCTORS AND PATIENTS AGREE: "BEST QUALITY SOUND" "LOWEST AFFORDABLE PRICE"

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"I have a \$2,000 ReSound Live hearing aid in my left ear and the MDHearingAid® PRO in my right ear. I am not able to notice a significant difference in sound quality between the two hearing aids."

—Dr. May, ENT physician

"They work so great, my mother says she hasn't heard this well in years, even with her \$2,000 digital! It was so great to see the joy on her face. She is 90 years young again." —Al P.

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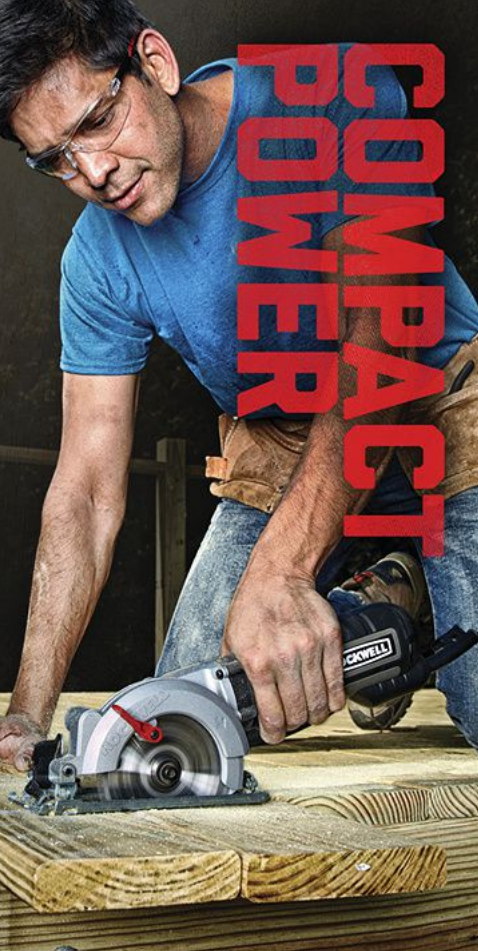


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PROJECT

warmth of the room. The crew sprayed R54 foam insulation all over the roof of the attic and onto the soffits to completely close things off. This brought the attic into the “envelope,” or the portion of the house controlled by the climate system, which fixes the condensation issue since there is now less movement of air between the family room and the attic. It also should knock at least 35 percent off our heating bill by relieving a bigger problem: the stack effect.

The stack effect happens in all buildings. As heat rises, it increases the air pressure on the higher floors. That air escapes via vents, cracks in the structure, or the open windows of residents frustrated by the temperature. Cold air rushes in on the ground floor to replace whatever is lost above. (This is actually why revolving doors were added to high-rises. With such a large stack effect, the air rushing to get in the front door can make a traditional door nearly impossible to push out and open.)

THE BOOKSHELVES

When he looked around the bookshelves, Stoltzfus found that condensation had caused mildew in the fiberglass we’d added. (This was bad news, but it was also a relief: For years we’d been trying to find the source of the slight smell in the front corner of the family room. We had looked everywhere, cleaned everywhere. Eventually we just didn’t let guests sit in the chair there.) Other than the putrid Styrofoam, there was no insulation at all around the bookshelves. Stoltzfus filled behind, above, and below the area with half-pound foam.

THE BASEMENT

Our basement is unfinished, with cinder-block walls and uncovered joists.

After spraying under the fiberglass lining the ceiling, Stoltzfus insulated the rim joists around the perimeter. Since our house is on a hill, nearly half of the walls are above grade. Using an infrared sensor we discovered that a lot of the cold air was being drawn in through these walls. To fix that, he sprayed just under 2 inches of foam (any more than that and you’re taking up useful space in case a future owner wants to put up a real wall) and covered it with a flame retardant. Stoltzfus did warn that there might be up to two weeks each year when it gets so cold outside that these walls will sweat, but after freezing for 19 years, we figured we could handle it.

CREDITS

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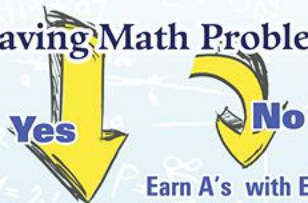
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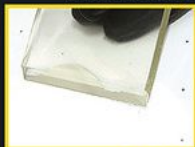
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MARBLE RUN

A project to build with your children.

DESIGNED BY JAMES SCHADEWALD

Materials

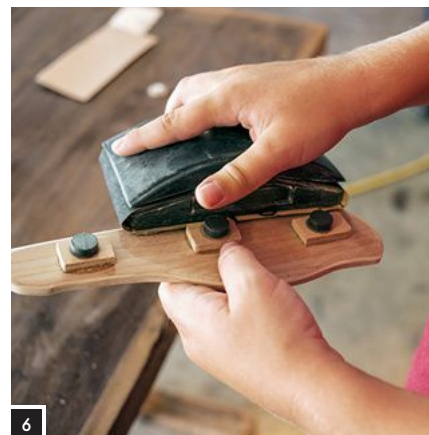
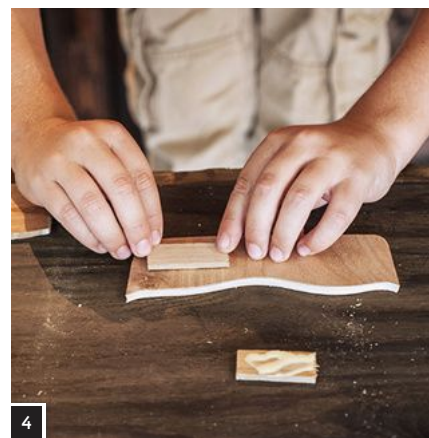
QTY	DESCRIPTION
1	quarter sheet of ¼-inch birch plywood
1	pkg. (40 pcs) button magnets
1	bottle carpenter's glue or craft adhesive
1	bag marbles
	60-, 80-, and 120-grit sandpaper

Instructions

● parent only
● parent and kid
● kid only

1. After an adult rips a ¾-inch-wide strip from the plywood, use the rest for drawing ramp shapes—straight lines, rolling curves, ski jumps. Be sure to make one that has a lip on both ends. This piece will catch the marbles at the bottom of each run.
2. Clamp the plywood to a workbench and use a jigsaw and a curve-cutting blade to cut out the ramp shapes. Smooth off any rough edges of the pieces using 80- and 120-grit sandpaper.
3. Crosscut the ¾-inch-wide strip into spacer blocks, which will go behind your ramp pieces. Using a simple and inexpensive hand miter saw (such as the Stanley 20-600, pictured) enables younger woodworkers to participate.
4. Glue two spacer blocks and magnets to the back of each ramp. You can use more for larger pieces. Be sure that the blocks are glued so that they don't project out over the edge of the ramp and interfere with the marble as it rolls.
5. Place a board and a weight of some kind on top of each ramp and the spacer blocks to provide pressure and a better glue bond. Allow the glue to dry for a couple of hours.
6. Bevel the back edge of each ramp using 60- and 80-grit sandpaper wrapped around a block of wood, or use a rubber sanding block. The beveled edge provides a secure track for the marble to roll in.

Turn the page for the finished product and schematic diagram



SEE PREVIOUS PAGE
FOR INSTRUCTIONS

OUR BUILDER
Seth Hensinger is a
seven-year-old from
Pennsylvania.



MARBLE RUN!

A project to build
with your children.

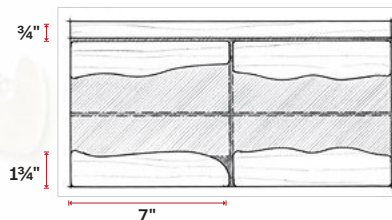
DESIGNED BY
JAMES SCHADEWALD

Difficulty: EASY REASONABLE HARD
Time: 2 hours Ages: 6+

PROJECT NOTES

THE CLATTER WILL eventually drive you nuts, but this magnetic marble run is infinitely reconfigurable—and a lot of fun. Finding a mounting surface is easy, considering that most of us have refrigerators in our homes. For the tracks, initially we thought we'd use PVC pipe. Then we tried to cut PVC in half lengthwise. It was tedious and much too hard to do without creating an elaborate jig, so we switched to wood.

The beveled edge of the track came about through trial and error. Our first attempts were on unbeveled wood. The marble would roll on it, but it wasn't as secure. Occasionally the marble even fell off the track. The 45-degree bevel turned out to be essential—especially as the ramp shapes got more complicated. Finally, there was the matter of how to stop the marble at the end of the ramp. Catching it wasn't an option. (We lost a few under the oven.) We tried a simple box, but that stuck out too far and took more time to build. That's when we decided to create the U-shaped final piece with a peak on either end. There was something satisfying about having the marble fall into an actual box, but really, you just want to finish the work and start playing with this thing.



After you cut a $\frac{3}{4}$ -inch strip off the plywood, the rest should be used to design shapes for the marble run.

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